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Illinois Agricultural Pesticides Conference '89

Summaries of Presentations
January 3, 4, & 5, 1989
Urbana, Illinois

Cooperative Extension Service
University of Illinois
at Urbana-Champaign
College of Agriculture
in cooperation with the
Illinois Natural History Survey

Cooperative Extension Service
University of Illinois at Urbana-Champaign
Helping You Put Knowledge to Work

The Illinois Agricultural Pesticides Conference is an annual program presented primarily for commercial pesticide applicators and dealers, but it is open to anyone in agriculture who has an interest in using pesticides in a crop pest management program. The conference promotes the proper, timely, and wise use of pesticides within an integrated crop management system. The program is presented by the University of Illinois at Urbana-Champaign, College of Agriculture, the Cooperative Extension Service, and the Illinois Natural History Survey. We gratefully acknowledge the assistance of the Illinois Department of Agriculture, the Illinois Fertilizer and Chemical Association, and the Illinois Agricultural Aviation Association in planning and staging the program.

This publication contains summaries of the presentations made at the Illinois Agricultural Pesticides Conference on the dates indicated on the front cover. Many of these summaries are research reports that are intended to bring you the latest research information about agricultural pest control. Some of the chemicals discussed in the summaries are not registered for use by the public and thus are not intended as recommendations. The Illinois Pest Control Handbook contains suggestions for using registered pesticides. The use of trade names does not constitute endorsement by the University of Illinois, nor does it imply discrimination against other products.

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Acknowledgments

The compilation and publication of these proceedings require considerable coordination and cooperation among several units in the College of Agriculture at the University of Illinois. Without the dedication of the individuals involved in this effort and the cooperation of the many authors, the papers it contains could never be published as a whole. The following is a list of the people responsible for the production of the *Proceedings of the Illinois Agricultural Pesticides Conference 1989*.

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Illinois Agricultural Pesticides Conference '89

The **Illinois Agricultural Pesticides Conference** is an educational program sponsored by the following organizations:

Cooperative Extension Service
College of Agriculture
University of Illinois

Illinois Natural History Survey
Illinois Department of Agriculture
Illinois Agricultural Aviation Association
Illinois Fertilizer and Chemical Association

The **planning committee** for the Illinois Agricultural Pesticides Conference '89 consists of the following people:

Kevin Steffey and **Don Kuhlman**
Extension Entomology, University of Illinois and Illinois Natural History Survey
Loren Bode
Agricultural Engineering, University of Illinois
Walker Kirby
Extension Plant Pathology, University of Illinois
Ellery Knake and **Marshal McGlamery**
Extension Weed Science, University of Illinois
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McLean County Agricultural Extension Adviser, Cooperative Extension Service, University of Illinois
Ron Waldrop
Lawrence County Agricultural Extension Adviser, Cooperative Extension Service, University of Illinois
Mark Igoe
Illinois Agricultural Aviation Association

Illinois Agricultural Aviation Association

Room 261, Illini Union
9:00 a.m. to 12:00 m.

Industry Session

Illini Rooms A and B, Illini Union

1:00 p.m. Welcome, *G. Thomas*

Herbicide Carryover: Perspectives from Industry

Rod Dorich Presiding

1:20 p.m. Herbicide Carryover—An Overview, *M. McGlamery*

CIBA-Geigy, *E. Cowett*

Elanco, *K. Burnside*

FMC, *L. Dobbins*

DuPont, *M. Duffy*

American Cyanamid, *M. Walmsley*

Questions and Answers

3:00 Break

New Developments from Industry

Bob Wolf Presiding

3:20 p.m. Valent, *H. Shepherd*

3:30 Uniroyal, *E. Foland*

3:35 Sandoz, *L. Bozeman*

3:40 Rhone-Poulenc, *W. Striegel*

3:48 Monsanto, *D. Schroeder*

3:58	ICI Americas, *D. Chaney*
4:06	FMC, *S. Barry*
4:15	Break
4:20	Elanco, *R. Mann*
4:30	DuPont, *R. McKelvey*
4:40	Dow, *R. Dorich*
4:50	American Cyanamid, *B. Gentsch*
5:00	CIBA-Geigy, *D. Taylor*
5:10	BASF, *B. Freed*
5:20	Adjourn to the **Mixer**

Mixer

Illini Room C, Illini Union
5:20 p.m. to 7:00 p.m.

This mixer is sponsored by the Illinois Fertilizer and Chemical Association and is intended for you to meet the speakers, sponsors, and committee members in an informal atmosphere. If you have any questions for the speakers who made presentations today or if you just want to visit with friends, please stop by.

General Session

Illini Rooms A, B, and C

Gene Thomas Presiding

8:00 a.m.	Trends in Pesticide Use in Illinois, *D. Pike*
8:15	Improving Herbicide Tolerance in Soybeans, *R. White*

Herbicide Carryover: Perspectives from the Universities

8:27 a.m.	Soil Factors Affecting Herbicide Residual Activity, *P. Shea*
8:47	Environmental Effects on Herbicide Performance and Residual, *M. Owen*
9:07	Detecting Herbicide Residues and Interpreting Results, *B. Curran*
9:27	Avoiding Herbicide Carryover Problems, *E. Knake*
9:47	New Methods for Herbicide Detection, *F. Koppatschek*
9:57	Break

The Drought of 1988: Pest Outlook and Management for 1989

Earl Kingman Presiding

10:15 a.m.	The Impact of Charcoal Rot of Soybeans on the 1988 Crop, *D. Eastburn*
10:25	The Spider Mite Outbreak of 1988: Did We Learn Enough to Improve Our Decision-Making Capabilities? *M. Gray*
10:45	Pesticide Application Mishaps in 1988, *B. Anderson*

11:00	Environmental Factors Influencing Corn Rootworm Biology and Control, *G. Sutter*
11:15	Insect Management: Making Decisions for Unique Circumstances, *R. Weinzierl*
11:35	Effects of the 1988 Drought on Plant Diseases for 1989, *M. Shurtleff*
11:50	Effects of the 1988 Drought on Insects for 1989, *D. Kuhlman*
12:05 p.m.	Lunch

Keynote Session: Issues and Regulations That Will Affect Pesticide Use

Loren Bode Presiding

1:00 p.m.	FIFRA Reauthorization: Salient Provisions Affecting Agrichemical Dealers and Pesticide Users, **(To Be Announced)**
	Riding the First Car on the "Thriller," **C. Sine**, Vice President and Editorial Director, Meister Publishing Company
	Will Sustainable Agriculture Have An Impact on Pesticide Use? **P. Bloome**, Assistant Director, Illinois Cooperative Extension Service
	The Risk of Risk Assessment, **V. Houk**, Director, Center for Environmental Health and Injury Control, Centers for Disease Control
3:00	Break

Ron Waldrop Presiding

3:15 p.m.	Wild Garlic Control, *G. Kapusta*
3:30	What Is New in Weed Control for 1989? *M. McGlamery*

Program—Wednesday, January 4

3:45	Management of Corn Rootworms: Research and Recommendations, *K. Steffey*
4:05	The Illinois Insecticide Evaluation Program: Results of Field Trials with Black Cutworms, Corn Rootworms, and European Corn Borers, *K. Kinney*
4:25	Timing of Fungicide Applications for Control of Common Rust on Sweet Corn Hybrids with Various Levels of Partial Resistance or Susceptibility, *J. Pataky*
4:40	On-Board Impregnation and Other Developments in Application Technology, *M. Broder*
4:55	Weed Interference, *E. Stoller*
5:10	Update on Sudden Death Syndrome, *W. Kirby*
5:25	Adjourn

Pesticide Applicator Training for Field Crop and Demonstration and Research Pest Control Categories

Room 314, Illini Union
7:30 p.m. Wednesday Evening

Concurrent training sessions for the field crop and research and demonstration pest control categories will be offered. Comprehensive training will include safe handling of pesticides, pesticide poisoning, pest identification, calibration, pesticide issues, and laws and regulations.

A person desiring to become certified as an applicator must first take and pass the General Standards examination before taking any of the applicator category examinations. However, there will be no training for the General Standards examination. Manuals and handout material will be available.

Bill Simmons Presiding

8:00 a.m.	Limiting Potential Hazards from Pesticides with What You Wear, *M. Sohn*
8:15	Retail Dealers' Responsibilities Under OSHA's Hazard Communications Standard, *V. Thompson*
8:30	USEPA Pesticide Strategy Plan: Illinois's Response, *R. Schwarberg*
8:50	Groundwater Contamination in the Vicinity of Agrichemical Mixing and Loading Facilities, *T. Long*
9:05	Pesticide Degradation Rates at Agrichemical Spill Sites, *A. Felsot*
9:20	State-of-the-Art Facilities for Containment and Mixing Sites, *M. Broder*
9:35	Illinois's Proposed Secondary Containment Regulations, *R. Schwarberg*
9:47	Developing a Groundwater Protection Plan, *W. Simmons*
10:05	Break

Mark Igoe Presiding

10:20 a.m.	The Plant Clinic: How We Can Help in Troubleshooting and Problem Resolution, *N. Pataky*
10:35	Getting Herbicides Past Crop Residue, *L. Wilbourn*

Program—Thursday, January 5

10:47	Insects in Stored Corn: Updates on Insecticide Resistance and Management Alternatives, *R. Weinzierl*
10:57	Fungicides for Control of Grain Storage Molds, *D. White*
11:12	Deposition Efficiency from Application of Postemergence Herbicides, *L. Bode*
11:27	Selecting Adjuvants for Postemergence Herbicides, *L. Wax*
11:42	Postemergence Grass Control in Corn, *R. Liebl*
11:57	Bushnell: A Case for Cross-Connection Control, *E. Ackerman*
12:09 p.m.	Control of Canada Thistle and Hemp Dogbane, *M. Orfanedes*
12:25	Adjourn

Pesticide Applicator Examinations

Room 314, Illini Union
1:15 to 4:30 p.m. Thursday Afternoon

Written examinations for all commercial pesticide applicator pest control categories will be offered. General Standards examinations will also be available. A person may take as many examinations as he or she can complete during the allotted time. A passing score of 70 percent is required on both the General Standards and category examinations in order to become a certified applicator.

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Pesticide Training and Certification Clinics--1989

Commercial Pesticide Training and Certification Clinics will be offered throughout the state with some program changes. Most of them will be two-day clinics with general standards training and testing on the first day. Only general standards tests may be taken on the first day; there will be a testing session on the second day in which any category test and the general standards test may be taken. Through most of the state and for all of the Field Crops Clinics, general standards training will be followed by category training from 2:00 to 5:00 p.m. on the first day with category training continuing from 8:00 a.m. until noon on the second day.

These clinics will include information on the Endangered Species Act and the groundwater contamination problem with representatives from the Illinois Environmental Protection Agency presenting updated information. Included in the presentations on insects, weeds, diseases, and calibration will be additional updated information to help keep you on the "cutting edge" of new developments in these fields.

Training Instructions

The Cooperative Extension Service of the University of Illinois writes the study guides and teaches the training sessions.

Pesticide training clinic questions should be sent to Phil Nixon, University of Illinois, 172 Natural Resources Building, 607 E. Peabody Drive, Champaign, Illinois 61820, telephone (217)333-6650. In northeastern Illinois, call the telephone number listed for that clinic's preregistration.

Study guides can be purchased from county Cooperative Extension Service offices and from the University of Illinois office listed above. They will also be available at each clinic. Illinois Pesticide Applicator Study Guides are available for general standards, and category manuals are available for turf, ornamentals, field crops, and rights-of-way. Study packets for other categories are also available, but only from the above University of Illinois campus address.

Testing Instructions

The State of Illinois Department of Agriculture administers both the general standards and category examinations. Illinois law requires a person who applies a pesticide for hire outside of a structure to be licensed by the Illinois Department of Agriculture.

Testing, certification, and licensing questions should be sent to Bill Anderson, Illinois Department of Agriculture, State Fairgrounds, Springfield, Illinois 62708-4906, telephone (217)785-2427. In northeastern Illinois, Stan Smith can be contacted at (312)990-8256.

1989 PESTICIDE TRAINING AND CERTIFICATION CLINICS

A $10.00-per-clinic registration fee is payable at the door of each clinic. One fee covers both days of two-day clinics. Registration begins at 7:30 a.m.

Schedule of two-day clinics:

First Day

8:00 a.m.-2:00 p.m.	General standards training
2:00 p.m.	General standards testing only
2:00-5:00 p.m.	Category training begins.

Second Day

8:00 a.m.-noon	Category training continues.
1:00 p.m.	Testing (all categories and general standards)
	Rights-of-way training during morning of second day only.

At one-day clinics, training begins at 8:00 a.m. Testing in all categories begins at 2:00 p.m. in Mt. Vernon and Bloomington, and at 1:00 p.m. in Kankakee and Belleville.

Date	City	Categories	Location
Jan. 9-10	Springfield	G.S., Turf, Orn, ROW*	Regional Extension Office, State Fairgrounds
Jan. 11-12	Rockford	G.S., Turf, Orn, ROW	Clock Tower Hotel, I-90 & Bus. 20
Jan. 31- Feb. 1	DeKalb	G.S., Field Crops	DeKalb Co. Extension Office, 315 N. 6th St.
Feb. 14-15	Jacksonville	G.S., Field Crops	Black Hawk Restaurant, Rt. 104
Feb. 16-17	Galesburg	G.S., Field Crops	Econolodge, 2 mi. west of I-74 on U.S. 34
Feb. 22-23	Mt. Vernon	G.S., Field Crops, Turf, Orn, ROW	Ramada Inn, I-57 & I-64
Feb. 27-28	Champaign	G.S., Field Crops, Turf, Orn	Round Barn, 1 block west of Mattis on Rt. 10
Mar. 1-2	Fairview Hts.	G.S., Turf, Orn	Ramada Inn, I-64 & Rt. 159
Mar. 6-7	Moline	G.S., Turf, Orn, ROW	Holiday Inn, Airport exit at I-74 & I-280
Apr. 12	Mt. Vernon	G.S., Mosquito	Community Center, City Park, 27th & Logan
Apr. 14	Bloomington	G.S.	Jumer's Chateau, Veterans Parkway
May 1	Kankakee	G.S., Mosquito	Kankakee Community College on River Road
May 4	Belleville	G.S., Mosquito	Farm Bureau, 407 E. Lincoln

*G.S. = general standards; Orn = ornamentals; ROW = rights-of-way.

1989 NORTHEASTERN ILLINOIS PESTICIDE CLINICS

A $10.00 per day *prepaid* registration fee is required at all times except for June 6--*no refunds*. Call the telephone number listed for the clinic that you wish to attend to obtain prepayment instructions. Registration begins at 8:00 a.m. Training begins at 8:30 a.m. Testing begins at 1:00 p.m. except for June 6. For two-day clinics, general standards training will be on the first day, turf and ornamentals training on the second day.

Date	City	Categories	Location
Feb. 7	Gurnee	G.S.	Days Inn, 5550 Grand Ave. Call (312)223-8627.
Feb. 14	Park Ridge	G.S.	VFW Hall, Higgins & Canfield Rds. Call (312)991-1160.
Feb. 21	Alsip	G.S.	Condesa del Mar, 12220 S. Cicero Ave. Call(312)532-4369.
Feb. 28- Mar. 1	Glencoe	G.S., Turf, Ornamentals	Chicago Botanic Garden, Lake-Cook Rd. east of I-94. Call (312)991-1160.
Mar. 7-8	Joliet	G.S., Turf, Ornamentals	Holiday Inn, Larkin Ave. & I-80. Call (815)727-9296.
Mar. 14	Crystal Lake	G.S.	Hob Nob II Restaurant, Rt. 14 & 31. Call (815)338-3737.
Mar. 28-29	Western Springs	G.S., Turf, Ornamentals	Lyons Twp. High School--So. Campus, Willow Springs Rd. & 49th St. Call (312)991-1160 to preregister.
Apr. 11-12	Wheaton	G.S., Turf, Ornamentals	DuPage Co. Fairgrounds, Manchester Rd. Call (312)682-7486.
Apr. 18-19	Glencoe	G.S., Turf, Ornamentals	Chicago Botanic Garden, Lake-Cook Rd. east of I-94. Call (312)991-1160.
Apr. 25-26	Alsip	G.S., Turf, Ornamentals	Condesa del Mar, 12220 S. Cicero Ave. Call (312)532-4369.
June 6	Wheaton	G.S.	DuPage Co. Fairgrounds, Manchester Rd. Preregistration not required. Testing at 12:30 p.m. All tests available.

G.S. = general standards.

For testing sessions, please bring your most current license or all past test results. You must pass the general standards certification examination before you will be allowed to take a category examination. Tests will be graded and results made available immediately after testing.

Testing sessions immediately following general standards training will include general standards testing only except on April 12 and 14, May 1 and 4, and June 6. On those dates, as well as during testing sessions following category training, all tests, including general standards, will be available.

Testing Only Sessions--All Tests Available

Dates: November 28, December 14, 1988; March 14 and 29, April 5 and 26, 1989; 8:30 a.m.-noon. Location: Illinois Department of Agriculture Building, State Fairgrounds, Springfield.

Workshops Offered in 1989

FIFTEENTH ANNUAL ILLINOIS CROP PROTECTION WORKSHOP

Extension specialists and research personnel with the University of Illinois, College of Agriculture, and the Illinois Natural History Survey are offering a Crop Protection Workshop from March 7 to 9, 1989, at the Chancellor Hotel and Convention Center, Champaign, Illinois. Advance registration will be required.

The objectives of the workshop are to give in-depth training in diagnosing pest problems, troubleshooting in the field, and identifying insect, weed, and disease pests, as well as life cycles, thresholds, plant nutrient deficiencies, and other factors that affect crop production decisions.

Specialists in entomology, weed science, agronomy, plant pathology, and agricultural engineering from the University of Illinois and the Illinois Natural History Survey will conduct training sessions on the above topics. Out-of-state speakers will also give presentations on subjects of particular interest. About eighteen hours will be spent in group sessions.

The registration fee for the workshop is $60 and will include the cost of the workshop and two lunches, but will not cover lodging. Further information about the workshop can be obtained at the registration desk at the Illinois Agricultural Pesticides Conference or from Michael Gray, 172 Natural Resources Building, 607 East Peabody Drive, Champaign, Illinois 61820; (217)333-6651.

FIELD CROP PEST MANAGEMENT SCOUT TRAINING SCHOOLS

A pest management scout training short course will be offered in 1989. This course is being offered to accommodate those persons who will monitor field crops for pest problems. The courses will be taught by Extension specialists in weed science, agronomy, entomology, and plant pathology from the University of Illinois and the Illinois Natural History Survey. The scout training school will be offered from March 20 to 22, 1989.

Further information about the workshop can be obtained at the registration desk at the Illinois Agricultural Pesticides Conference or from Bill Curran, (217)333-4424, or Michael Gray, (217)333-6651.

WHICH WORKSHOP IS FOR YOU?

Each year a number of people inquire about the difference between the crop protection workshop and the pest management scout training short course.

The Crop Protection Workshop is intended for those individuals who are concerned with the research that goes into pest management. Topics presented represent the current research and ideas that will provide the basis for future pest management decisions. Farmers, agribusiness people, and Extension advisers represent the largest portion of the 300 people in attendance.

The Field Crop Pest Management Scout Training Schools are intended for those who wish to learn the what, how, where, and when of field crop scouting. The lab sessions are approximately four hours each and cover the identification of weeds, insects, and plant diseases and the procedures needed to accurately scout and report the findings. Farmers and field scouts employed by private consultants comprise the largest segment of the audience.

If you are still unsure about which workshop to attend, contact Michael Gray, Illinois Natural History Survey, 172 Natural Resources Building, 607 East Peabody Drive, Champaign, Illinois 61820; (217)333-6651.

Newsletters from the University of Illinois College of Agriculture

FARM ECONOMICS FACTS AND OPINIONS--Economic principles applied to farm problems such as marketing strategies, crop and livestock production decisions, government and institutional policies. Eighteen issues per year.

WEEKLY OUTLOOK--Anticipates reports and interprets current market information--supply, demand, and price outlook--for agricultural products. Issued weekly except for last two weeks of December.

LIVESTOCK PRICES AND MARKETS--Forecasts of prices and production for hogs (four issues) and cattle (two issues) following inventory reports. Includes inventory data, forecasting methods, and discussions of pricing strategies. Six issues per year.

GRAIN PRICE OUTLOOK--Four issues each on corn and soybeans. An in-depth analysis of supply, demand, and price outlook for corn and soybeans. Also includes a discussion of storage and pricing strategies for producers. Eight issues per year.

ILLINOIS IRRIGATION NEWSLETTER--Presents information on new irrigation techniques and equipment; some in-depth treatment of specific topics of interest to irrigators. Ten issues per year.

SWINE REPORT--Current information on swine feeding, breeding, management, and engineering. Issued quarterly.

BEEF REPORT--Current information on cow/calf and feedlot management. Provides the latest research findings and timely tips for cow/calf producers and feedlot operators. Issued quarterly.

ILLINOIS DAIRY DIGEST--Provides the latest dairy research information available from the U of I and other sources; practical, timely tips to help producers make management decisions; announcements of educational events. Four issues per year.

SHEEP REPORT--Current information on breeding, feeding, management, and health. Research updates and current information on educational activities. Six issues per year.

ILLINOIS POULTRY SUGGESTIONS--Latest information on management, marketing, business and regulatory developments in the poultry industry. For hatchery operators, commercial poultry producers, small flock owners and poultry service personnel. Six issues per year.

BEES AND HONEY--Presents basic beekeeping information including research, statistics, diseases and pests, as well as timely tips. Issued quarterly.

ILLINOIS FOREST MANAGEMENT NEWSLETTER--Features helpful management information and timely tips for woodland owners on silviculture, tree planting, wildlife management, forest investments and taxes, marketing, harvesting and utilization, forest insect and disease problems, residential tree care and the care of wood products around the home. Two issues per year.

ILLINOIS VEGETABLE FARMER'S NEWSLETTER--Provides production, harvest and handling, and marketing advice for commercial producers in the Midwest. News and updates from university and Extension staff are highlighted. Four issues per year.

INSECT, WEED AND PLANT DISEASE SURVEY BULLETIN--Weekly reports on the current agricultural insect, weed, and plant disease situation with advice on control methods. Also covers new developments in pesticide application techniques. Issued weekly April-August.

HOME, YARD, AND GARDEN PEST NEWSLETTER--Insect, weed, and plant disease pests of the home and garden. Current controls, application equipment and methods, storage and disposal of pesticides, plus other topics. Issued weekly April-July; biweekly in August.

SPRAY SERVICE REPORT--Provides information on commercial fruit culture, insect and disease problems,and recommended control measures. Seventeen issues per year concentrated during the growing season. Issued weekly April-May; biweekly March and June; three-week intervals July-August; plus special issues October-March.

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Triazine Herbicide Carryover

E. Cowett

The lack of rainfall in many parts of the country during 1988 has increased the potential for triazine herbicide carryover during 1989. In light of this, you will be asked questions at your winter meetings about planting soybeans and other triazine-sensitive crops in 1989 in fields where atrazine or products containing atrazine were used in 1988. Furthermore, you will probably receive numerous calls from growers just prior to and during planting regarding the same issue. You will be expected to provide an answer immediately with a minimum of background information. The potential for atrazine carryover is increased in soils low in clay and organic matter content and in soils with a calcareous surface layer and a pH greater than 7.3. Carryover is also more likely if triazines were applied late, impregnated on dry fertilizer, or incorporated into the soil.

The intent of this paper is to suggest some practices you might recommend to concerned growers--practices that should reduce the potential for carryover problems. The most obvious recommendation is to plant corn again next year, but this is not always possible. If triazine-sensitive crops are going to be planted, recommend thorough tillage whenever possible. Thorough and uniform tillage may help alleviate hot spots by speeding up the rate of breakdown and distributing the herbicide more uniformly throughout the top 6 to 8 inches of soil. Also, emphasize to growers that they should not rotate to soybeans or other sensitive crops in any soils that have a calcareous surface layer.

Timing of application of the triazine herbicide last year is another factor that you should consider when you address the potential carryover issue. Those growers who used atrazine or products containing atrazine early preplant during 1988 are less likely to experience carryover problems. Finally, you may wish to suggest that fields subject to potential triazine carryover be used as set-aside acres, even though they might not obtain a good stand of the cover crop.

Undoubtedly, some growers will call you a few days before planting and request that you take soil samples for triazine analysis. Turnaround time for analytical results is sometimes slow. Chemical analysis is also quite expensive. If it is absolutely essential that the soil be analyzed and you have a couple of weeks, I suggest that you send the sample to an independent testing laboratory or to the state laboratory.

You might be able to avoid some of the problems associated with soil chemical analysis by recommending that growers or dealers conduct simple bioassay tests a few weeks before planting. Two methods of conducting bioassays that have been developed will be described during my presentation. After completing one or the other of these bioassay tests, the grower can determine what crops can and cannot be planted. Always remind growers that the accuracy of this test is dependent upon the accuracy of their soil sampling techniques and upon good maintenance of the seedlings during the test period.

You may be asked to make a recommendation about rotating to soybeans based upon results of a soil chemical analysis. As a general rule, soybeans should not be planted if the soil has a concentration of total triazines of 0.18 parts per million (ppm) or greater. If the soil has a calcareous surface layer and a pH of 7.3 or greater, only corn or sorghum should be planted if total triazine residues of 0.12 ppm or more are found.

Rotational Crops Following 1988 Treflan and Sonalan Applications

K. Burnside

The dry conditions experienced during the 1988 growing season have raised concerns about recropping practices. One particular concern is whether winter wheat or corn can be planted in fields treated in 1988 with certain soybean herbicides.

Based on extensive research by Lilly Research Laboratories and others, as well as many years of experience under a wide range of extreme weather conditions, Elanco remains confident in the validity of the current Treflan label recommendations.

When the normal labeled rates of Treflan (1 pt on coarse soils, 1 1/2 pt on medium soil, and 2 pt on fine soil) have been used, Treflan will not carry over to adversely affect the yield of wheat planted in the fall of 1988 or corn planted in the spring of 1989.

If a special-rate program (higher than normal rates) has been used and extremely dry conditions have been experienced, certain precautions and good cultural practices should be used to minimize all potential crop stress factors. Such practices include deep tillage, avoiding soil compaction, good seedbed preparation, good fertility practices, planting high-quality certified seed, and planting when favorable soil moisture and temperature conditions exist.

Refer to the Treflan label for special precautions for the double-rate and special-rate programs and for certain crop rotations in specific geographic areas.

When Treflan has been used in combination with another herbicide, refer to the recropping recommendations of the other product's manufacturer and follow the most restrictive recommendation.

When Sonalan has been applied at recommended label rates, it will not carry over to injure corn, milo, wheat, or barley.

When Sonalan has been used in combination with another herbicide, refer to the recropping recommendation of the other product's manufacturer and follow the most restrictive recommendations.

Assessing Carryover Potential of Command

L. Dobbins

In 1988, much of the Midwest experienced extremely dry conditions that reduced herbicide performance and lowered crop yields. The same dry conditions are now raising concerns about the impact of herbicide carryover on rotational crops.

Many factors may affect the carryover potential of soil-applied herbicides: mode of breakdown, solubility, soil affinity, soil type, pH and organic matter, tillage, type or variety of rotational crop, soil moisture, and weather conditions. The number of potential interactions among these factors makes the occurrence of carryover uncertain.

In early research with Command® 4 EC herbicide, the observation of carryover symptoms on rotational crops occurred sporadically. However, because the symptoms were so obvious, attention was focused on this potential problem early in the product's development. If the symptoms had been less obvious, as in the case of root inhibition, they may have gone unnoticed for a period of time. Research was conducted to determine the potential frequency of carryover and subsequent effects on rotational crops. The frequency of bleaching symptoms and, more importantly, frequency of stand loss were considered to be high enough to warrant restrictive labeling for some crops, such as wheat. Corn, on the other hand, was found to be much more tolerant and was included as a rotational crop on the product label.

Through research, we have learned that the occurrence of carryover symptoms with Command 4 EC, as with most herbicides, is difficult to predict. We have also learned that the only symptom of Command 4 EC activity in the plant is the bleaching of leaf tissue. Efforts to create carryover symptoms through the use of exaggerated rates, up to 3 pounds of active ingredient per acre, have proved only marginally successful. Only five of our thirteen "controllable factors" trials, established to determine cultural practices and other factors that could be manipulated to affect carryover on field corn, had measurable symptoms in spite of the high use rates. This frequency relates well to the occurrence of carryover in commercial use where less than 1 percent of treated acres has been affected. Of the factors evaluated in the trials, some were found to have a slightly enhancing effect on the expression of bleaching symptoms. High use rates, incorporation of a late season application, early planting of a sensitive hybrid, and low pH all play a part by interacting with the other factors discussed earlier. However, manipulation of any or all of the controllable factors did not prove completely effective.

Because changing the manipulable factors did not assure that symptoms would not occasionally be seen, it became important to better understand the potential ramifications of the symptoms. Many trials have been established by FMC and university researchers to determine if the expression of carryover symptoms on corn would result in a decreased yield. Results have been very favorable. At labeled and sometimes higher use rates, there has not been a significant difference in yield when compared to other herbicide treatments used as standards for comparison.

The conclusion drawn from available information, both experimental and commercial, is that at labeled use rates, Command 4 EC has been associated with occasional white plants in the young corn crop. The symptoms are transient in nature and would not be expected to result in any significant impact on plant stand or yield. The best advice for the coming crop year is to follow good agronomic practices, making corrective changes when necessary, to ensure the best growing conditions possible.

The Effect of Drought Conditions on Chlorimuron Ethyl Degradation

M. Duffy

The drought conditions throughout much of the Midwest during the spring and summer of 1988 have raised concerns about the extent of herbicide breakdown and the potential for carryover and injury to 1989 rotational crops. We have used a combination of laboratory and greenhouse studies, field experience, and computer simulations to predict the impact the drought will have on chlorimuron ethyl degradation and its potential for carryover.

The principal modes of degradation of chlorimuron ethyl in soil are chemical hydrolysis and microbial breakdown. Soil temperature, pH, and moisture are the factors having the greatest influence on these processes. The rate of chemical hydrolysis increases about 2.5-fold for every 10°F rise in temperature. Microbial breakdown also accelerates with increasing temperature. However, when temperatures of 100° to 110°F are reached, this trend stops and microbial metabolism begins to slow.

Soil pH exerts a significant influence on the rate of chemical hydrolysis. As pH decreases, the rate of chemical hydrolysis increases. Lowering the pH by 0.2 units results in about a 1.4-fold increase in the rate of chemical hydrolysis. Microbial breakdown has not been correlated to soil pH. Although relative populations and distribution of microbes are dependent on soil pH, we have found little change in the rate of microbial degradation of chlorimuron ethyl in a variety of microbially active soils with diverse pH and organic-matter contents. These results indicate that many species of microorganisms can degrade chlorimuron ethyl.

The influence of soil moisture is more subtle. As the moisture content of the soil approaches the permanent wilting point (15 bar), the remaining soil solution decreases in pH. This reduction in pH, as noted above, will cause an increase in the rate of chlorimuron ethyl chemical hydrolysis. Chlorimuron ethyl will therefore degrade more rapidly via chemical hydrolysis in drier soils than when moisture is more abundant. By contrast, in drier soils microbial activity is diminished. This leads to a significant decrease in the rate of microbial breakdown of chlorimuron ethyl.

Sorption of herbicides in general, and for chlorimuron ethyl in particular, increases with increasing soil organic-matter content. If all other factors are comparable, the potential for recrop injury following an application of chlorimuron ethyl will be lower in a higher organic-matter soil compared to one of lower organic-matter content where sorption is less and a greater fraction of the residual herbicide is available for plant uptake.

In an effort to understand the interaction among these key variables, DuPont's computer dissipation model was used to simulate the degradation of chlorimuron ethyl and its potential for carryover to corn in 1989. Simulations were conducted for several locations using actual 1988 weather data and soil properties characteristic of the specific locations. Our results indicate that, although microbial metabolism is an important degradation pathway, the decreased microbial breakdown during the drought of 1988 can be compensated for by the increased rate of chemical hydrolysis resulting from the higher than normal temperatures and lower than normal soil moisture. Furthermore, if ample soil moisture is available to support "normal" microbial activity for several weeks following application, the total degradation that is projected can sometimes exceed that expected in a year with average rainfall. Therefore, we expect that growers who used products containing chlorimuron ethyl according to label recommendations will not have any greater risk of rotational crop injury in 1989 because of dry conditions in 1988.

Drought Rotational Crop Management and Scepter Herbicide

M. Walmsley

The extreme and widespread drought conditions of 1988 have forced many growers to reexamine their crop production practices, especially their chemical use. Because many longer-lasting herbicides can cause carryover, growers need answers to help reduce future risks.

American Cyanamid Company is taking a leadership role by offering a list of cultural practices or crop rotation alternatives to help reduce the potential risk of Scepter® herbicide carryover. Because of the severe environmental conditions in 1988, Cyanamid recommends that, for many areas, farmers should not rotate to corn or wheat in 1989 on ground to which Scepter was applied in 1988. Growers with no other alternatives than to rotate crops in fields where Scepter was applied in 1988 should follow the prescribed management practices that follow.

CORN PLANTED IN 1989 WHERE SCEPTER WAS APPLIED IN 1988

Thoroughly mix the soil prior to planting to dilute potential residues and break up compaction layers. Fall tillage operations are most effective.

1. Use a chisel plow or mulch tiller with twisted shovels in the fall or early spring, leaving a rough surface to reduce wind erosion and increase snow retention. In spring, field cultivate once or twice to level the soil and to distribute any herbicide residues.

2. Use a tandem disk to thoroughly mix the soil and residue, leaving the surface rough to reduce wind erosion and increase snow retention. In the spring, field cultivate once or twice to level the soil and to distribute residues.

3. On level, heavy soils that are not subject to erosion, moldboard plowing will help dilute or dissipate any potential residues. In the spring, field cultivate once or twice to level the soil and to distribute residues.

Where possible, avoid using no-till and ridge-till planting methods. If these methods must be used, use furrow openers or other devices that move potentially harmful residues away from the seed furrow.

Determine fertility levels of all fields to be planted to corn. Fertilize and lime to ensure that nutrient levels and soil pH are optimum for yield goals that have been established. Fall applications of anhydrous ammonia are preferred over spring applications. Be sure that soil pH is above 6.0 to ensure good corn growth.

Use a starter fertilizer with side-band placement to enhance early-season plant growth and development.

Establish a good seedbed to ensure maximum soil/seed contact.

Plant at optimum planting dates for your area. Allow soil temperatures to reach optimum levels (55°F or higher) for rapid corn germination and early plant development.

Plant corn 1 1/2 to 2 inches deep, regardless of soil conditions or anticipated rainfall. Due to the variability that exists among planter boxes on the same tool bar, verify that proper planting depth is achieved.

Plant adapted corn hybrids that are known for tolerance to stress and drought. Use certified seed with a seed germination rating of at least 90 percent. Do not plant seed corn, popcorn, or sweet corn in fields where Scepter was applied in 1988.

Cultivate early to mix the soil again.

Use an approved insecticide-nematicide to protect seedling plants from early-season pests, including wireworms, white grubs, and other insects that may damage the root system.

Adequate moisture or rainfall following planting and early in the season allows for rapid and vigorous growth of young corn plants. Healthy, robust corn plants will tolerate and more effectively metabolize Scepter residues.

WHEAT PLANTED IN 1989 WHERE SCEPTER WAS APPLIED IN 1988

If wheat is planted in a field where Scepter was applied in 1988, Cyanamid offers these prescribed cultural practices to minimize potential risk.

For fall-planted wheat, thorough mixing of the soil prior to planting is recommended to dilute residues and break up compaction layers. Use a chisel plow, tandem disk, or, where feasible, a moldboard plow to mix soil and residue. For spring wheat, leave the soil rough to reduce wind erosion and increase snow retention.

Determine fertility levels of all fields to be planted to wheat. Fertilize and lime to ensure that nutrient levels and soil pH are optimum for yield goals that have been established. The soil pH should be above 6.0 to ensure good wheat growth.

Establish a good seedbed to ensure maximum soil/seed contact.

Plant at optimum planting dates for your area. Adequate moisture or rainfall following planting and early in the season allows for rapid and vigorous growth of young wheat. Although crop injury is unlikely to occur, wheat will grow out of early-season injury and will produce normal yields under normal growing conditions.

Trends in Pesticide Use in Illinois

D. Pike

Over the last 20 years, the farmers in the state of Illinois have been leading consumers of agricultural pesticides. Although the overall quantity of pesticides used within the state, as well as the use of many individual pesticides, has declined in recent years, the total number of treated acres has been increasing. There are two primary reasons which explain why this inverse relationship is possible. First and foremost, many of the newest pesticides are effective at much lower application rates, making it possible to obtain comparable pest control with less product. Second, there has been an increasing availability of products that are effective after the presence of the pest has been detected, making it possible to reduce unnecessarily heavy application rates for early season prevention.

Surveys conducted over the last 15 years show that plowing, crop rotation, rotary hoeing, and cultivation continue to be important parts of pest control on Illinois farms. Conservation tillage practices and erosion awareness, however, have contributed to an overall decrease in the amount of tillage done on cropland and, in some instances, to an increase in the amount of pesticides used on those acres.

Improving Herbicide Tolerance in Soybeans

R. White

Weed control as a science has advanced greatly over the past 40 years, accompanying the progress made in other disciplines related to crop production. The greatest advancement in weed science has occurred in the area of herbicide development, that is, the introduction and use of more selective and phytotoxic chemicals. As a result, herbicides have become the most effective means of controlling weeds. However, farmers continue to incur annual yield reductions due to weed interference. In 1984, the Weed Science Society of America estimated the annual expenditure for herbicide usage in the United States at $1 billion, and average annual soybean yield losses due to uncontrolled weeds at almost $2 billion. (The $3 billion does not include yield losses in other crops). Why do such efforts, expenditures, and losses continue with our present technology?

One of many possible answers to this question is the limited effectiveness of many currently used herbicides. Even with use rates declining from pounds per acre to ounces and grams per acre, soybean sensitivity to a herbicide remains the single factor that determines use rates for that herbicide, the objective being to avoid crop injury. Thus, one resolution to this situation would be to incorporate greater herbicide tolerance into soybean lines so that higher rates could be applied. Greater herbicide tolerance in soybeans (1) expands the uses of present herbicides not used in soybean cultures; (2) improves weed control effectiveness with greater use rates; (3) reduces the cost of weed control; (4) decreases the use of hazardous chemicals; and (5) decreases the threat of rotational crop injury from soil residues.

The increasing importance of developing herbicide-tolerant/resistant crop lines is reflected by the response of the agrichemical industry. Many chemical companies have recently acquired seed companies and initiated joint research ventures with newly established biotechnology companies. Current research efforts are directed toward discovering new and/or improved herbicides and developing resistant crop cultivars for future marketing. Universities across the United States have also increased their research investments in this area of weed science.

The accessibility of herbicide-resistant soybeans increases as the knowledge of herbicide mechanisms of action becomes more complete and as advances continue in the area of genetic engineering. Mechanisms conferring herbicide tolerance are often based on biochemical differences between a susceptible and tolerant plant at the site of action. Thus, these favorable traits are genetically based and can therefore be manipulated as such. Biotechnological advances made in recent years have provided new options and alternate approaches for developing herbicide-tolerant soybeans. They have stimulated interest, desire, and the probability of progress in this area of weed science. There are many techniques directed at these processes (usually enzymatic) that are used to develop herbicide tolerance:

1. target modification: incorporating a variant of the natural enzyme that is not affected by the herbicide (parallel enzymes).

2. degradation strategy: isolating a gene (enzyme) that detoxifies the herbicide into harmless metabolites.

3. gene amplification: producing multiple copies of the desired gene (that is, not all enzymes are inhibited by the chemical).

4. altered uptake, translocation, or compartmentalization: decreasing the concentration of herbicide reaching the site of action.

5. increased synthesis of a substrate able to reverse the herbicide-induced inhibition (for example, amino acids).

In general, it is possible that herbicide tolerance/resistance occurs naturally and is either present in the plant before it is ever exposed to the herbicide (the basis for weed/crop selectivity) or that it has developed after repeated exposure to the chemical (natural or *in vitro* selection). The single restriction of this phenomenon is that physiological resistance to any herbicide can only develop within the framework of metabolic processes that are present in the plant cell.

At the University of Illinois, researchers continue to investigate the presence of herbicide tolerance within the collection of perennial *Glycine* species. The most recent work has involved the screening of approximately 200 accessions of the wild *Glycine* species at the whole plant level for tolerance to 2,4-D. Increased levels of 2,4-D tolerance were distinctly present. Tissue cultures (callus and cell suspension) of the 12 most tolerant perennial species were initiated for screening at the cellular level. Results of all these studies indicated an inherent tolerance to 2,4-D approximately 5 to 10 times greater than that of the cultivated soybean. Further research (*in vitro*) has revealed that the perennial *Glycine* accessions have slightly reduced 2,4-D uptake and greater rates of 2,4-D metabolism as compared to *Glycine max*. Also, the resulting 2,4-D metabolites (amino acid and sugar conjugates) extracted from the cells differ between the annual and perennial soybean. Future research efforts will be directed toward identifying and characterizing the mechanism(s) conferring this increased level of 2,4-D tolerance. The long-term goals of this research are to incorporate this trait from the related wild species into *Glycine max* via genetic engineering or traditional plant breeding and to further understand the 2,4-D mode of action.

Soil Factors Affecting Herbicide Residual Activity

P. Shea

Soil-applied herbicides must have residual activity to be effective weed control agents, but excessive persistence can result in injury to rotational crops and increase the possibility of environmental contamination. Short-lived herbicides such as the carbamothioates EPTC (EPTC, Eradicane) and butylate (Sutan) may not persist long enough for adequate weed control at some locations. However, prolonged persistence of the triazine atrazine, the sulfonylurea chlorsulfuron (Glean), the imidazolinone imazaquin (Scepter), or some other herbicides may result in carryover and restrict rotational crop options. Each herbicide differs in susceptibility to degradation, vapor loss, solubility in water, and affinity for soil clay and organic matter. However, soil properties, climatic conditions, and management practices can greatly influence herbicide longevity and residual activity at a specific location.

HERBICIDE PROPERTIES

The unique physical and chemical properties of a herbicide that determine its activity and selectivity in plants are also largely responsible for its behavior and fate in soil. The most critical of these properties are solubility, polarity, volatility, and susceptibility to degradation. Water solubility increases with the polarity of the herbicide molecule and ranges from less than 1 part per million (ppm) for trifluralin (Treflan) and pendimethalin (Prowl) to greater than 80 percent for salt formulations of some herbicides such as the dimethylamine salt of dicamba (Banvel). More polar (hydrophilic or "water-loving") herbicides are less likely to partition out of solution onto soil surfaces than less polar (lipophilic or "fat-loving") herbicides. Important exceptions, however, are the cationic herbicides paraquat (Gramoxone), diquat (Diquat), and difenzoquat (Avenge), which are highly soluble but strongly adsorbed (bound) on clay cation exchange sites. Because water is the main herbicide carrier in soil, herbicides with higher water solubilities are generally more readily leached or transported away from the site of application in runoff.

Volatility is the tendency of a chemical to change from a solid or liquid to a gas. Volatilization losses are less for herbicides that have low vapor pressures (such as atrazine) than those with high vapor pressures (such as trifluralin or EPTC). However, vapor pressure increases with temperature, and high soil-surface temperatures will cause more volatilization of all herbicides. Thus, potential volatilization losses are generally less with early spring applications than for applications made later in the season when soil-surface temperatures can be very high. Vaporization will also increase with wind speed, and greater losses can be expected from an unprotected smooth soil surface than from a rough surface that tends to break the wind. Soil incorporation or immediate irrigation is usually recommended for highly volatile herbicides to reduce loss. Volatilization reduces the amount of herbicide residue in soil and can decrease persistence.

Herbicides can be degraded in soil by both chemical and microbial processes. Some herbicides, such as atrazine and chlorsulfuron, are susceptible to "acid-catalyzed hydrolysis" and are less persistent at low than high soil pH. The difference may be dramatic. For example, the half-life (time required for half of the total molecules to degrade) of chlorsulfuron may vary from less than 2 weeks at pH 5.5 to greater than 9 weeks at pH 7.5.

Other herbicides, such as trifluralin, are susceptible to photodecomposition on exposure to light. However, losses due to photodecomposition are generally only significant in water or on exposed plant and soil surfaces. All herbicides are susceptible to microbial breakdown, but their relative sensitivity can vary considerably. Herbicides such as the phenoxyacetic acids (2,4-D or MCPA, for example) have short half-lives because they can be degraded by a wide variety of soil microorganisms. Other herbicides are more persistent because only a few species of bacteria, fungi, or actinomycetes can degrade them. Microbial adaptation to repeated application of a herbicide may gradually increase the rate of degradation. If this occurs with short-lived herbicides such as EPTC or butylate, persistence may not be sufficient for adequate weed control.

Formulation can affect herbicide behavior in soil. Herbicides in water-soluble formulations can generally be expected to be more mobile than those formulated as emulsifiable concentrates (EC). Microencapsulated (ME) and some granular (G) herbicide formulations are designed to release herbicide over an extended period of time. This may increase the length of residual activity for weed control, but may also increase the possibility of carryover.

Herbicides with similar properties can be grouped into chemical classes or families. One important classification is based on herbicide polarity and response to soil pH. Acidic herbicides such as dicamba and chlorsulfuron lose a proton and become organic anions with increasing pH. Organic anions, like their inorganic counterparts NO_3^- and Cl^-, may be highly mobile in soil because of their high solubility and tendency to be repelled from negatively charged clay surfaces. Organic bases such as atrazine gain a proton and become organic cations with decreasing pH. Although organic cations are water-soluble, they can become strongly bound to the soil cation exchange, as are the inorganic cations Ca^{2+} and NH_4^+. This property promotes retention in surface soil and can effectively increase longevity. Ionically neutral herbicides whose solubility and soil adsorption are not influenced by soil pH are classified as nonionic.

SOIL PROPERTIES

Each soil contains a different proportion of sand, silt, and clay (texture) and varies in organic matter content, pH, and cation exchange capacity. Coarse-textured soils (such as sandy loams) have low water-holding capacities, and rapid leaching of water and dissolved solutes, including herbicides, can occur. Fine-textured soils have higher water-holding capacities and slower leaching rates.

Herbicide retention increases with clay or organic matter content as these constituents provide sites for adsorption. Acidic herbicides such as picloram (Tordon) and chlorsulfuron are not strongly bound and may run off or leach into the soil profile with water in response to gravity, or move up in response to evapotranspiration. Nonionic herbicides with low water solubilities such as trifluralin and pendimethalin are strongly adsorbed to organic matter and tend to remain near the soil surface. Nonionic herbicides with higher solubilities, such as alachlor (Lasso), metolachlor (Dual), and propachlor (Ramrod), are more mobile in some soils. Adsorbed herbicides may also be transported with small soil particles to which they are bound. This mechanism is not significant for nonpoint leaching but may be responsible for mass movement of herbicide through soil cracks and in runoff water.

HERBICIDE AVAILABILITY

Although strongly bound herbicides may be retained in surface soils for extended periods of time, they may not be available for plant uptake. Nonionic herbicides with low water solubilities have a high affinity for soil organic matter and may be ineffective in highly organic soils. The cationic herbicides paraquat and diquat are highly soluble but essentially unavailable to plants and microorganisms because they have a 2+ charge (like Ca^{2+}) and are held on the cation exchange by strong ionic bonds. In contrast, the availability of herbicides whose mechanism of adsorption is pH-dependent (organic acids and bases) can change with solution pH. Increasing pH will favor the movement of these herbicides from soil colloid surfaces into solution. This may explain greater residual herbicide phytotoxicity (or carryover injury) following a fall or early spring lime application.

SOIL pH

Solution pH in the vicinity of the plant root ("rhizosphere") may affect the uptake of acidic herbicides. The pH in this area may be higher or lower than that of the bulk solution, depending on plant species, nitrogen uptake, and solution buffering capacity. Uptake of acidic herbicides such as chlorsulfuron and imazethapyr (Pursuit) will be greater at lower solution pH.

There is also an optimum soil pH for microbial activity. Bacteria are generally most active between pH 6 and 7.5, while fungi tend to be less sensitive to soil acidity and are more active at lower pH. Thus, the effect of pH on herbicide degradation by soil microbes will depend on which organisms are able to degrade the compound. Fluctuations in soil pH following lime or fertilizer application can also temporarily decrease microbial activity and reduce the rate of herbicide degradation. This may increase herbicide carryover or reduce the rate of degradation of herbicide residues in the spring before planting a sensitive crop. Fertilizer or lime application near the time of herbicide application may similarly affect degradation. In some instances, it may be desirable to reduce degradation rate. For example, an increase in pH resulting from lime or urea application may increase the residual activity of short-lived herbicides such as EPTC or butylate.

As previously indicated, soil pH can greatly affect the chemical hydrolysis of herbicides such as atrazine and chlorsulfuron, which will be more persistent in alkaline than in acidic soils. In contrast, some of the organophosphate insecticides are quite sensitive to alkalinity and are less persistent at higher soil pH levels.

SOIL MOISTURE AND TEMPERATURE

Soil moisture can influence herbicide residual activity in several ways. Herbicides must be in solution to be available for plant uptake, microbial degradation, and movement in the soil profile. Moisture is also required for chemical degradation. Excess water may increase the total amount of herbicide dissolved in solution relative to the amount adsorbed.

Actively transpiring plants (in which water is moving from the soil to the leaves) can take up herbicides passively along with water. Herbicide concentration in solution will increase as soil moisture decreases, increasing the amount of herbicide taken up per unit of time if the plants are still actively transpiring. When the soil moisture level is low enough to reduce transpiration, herbicide uptake is reduced, and herbicide molecules will partition from the solution onto soil clay and organic matter surfaces. Rewetting the soil can reverse the process, but the amount of herbicide released into solution will be determined by the specific mechanism of retention on soil colloid surfaces, the amount degraded, the presence of soil micropores, and the extent of drying. Ionically bound herbicides and herbicides that are highly lipophilic may not be readily released. Also, some of the herbicide may have degraded. Other molecules may be trapped by air "bubbles" in small pore spaces not connected to the bulk solution. Volatile herbicides can move into soil air spaces on drying and may be lost to the atmosphere.

Soil moisture levels of about 60 percent of water-filled pore space ("field capacity") and temperatures above 15°C favor microbial degradation. Essentially no microbial degradation and little chemical degradation will occur when the ground is frozen or the soil is dry. Lower air temperatures decrease loss by evaporation and transpiration (evapotranspiration). Rainfall also increases loss of water-soluble herbicides from surface soil by leaching. Herbicides are most susceptible to leaching when excessive rainfall occurs shortly after application or when the soil is already wet. Cool, dry soils will have a greater potential for herbicide carryover than warm, moist soils.

MANAGEMENT PRACTICES

Herbicide rate, time and method of application, and tillage practices can affect herbicide residual activity and carryover. In general, higher application rates increase residual activity because more herbicide is present in the soil. However, carryover may not be directly proportional to application rate, at least not for spring-applied herbicides. Soil residues of atrazine detected in late fall may be the same for spring applications of 1 or 2 lb of the herbicide. The reduction in application rate required to significantly decrease fall herbicide residue levels may result in loss of efficacy. Conversely, an excessive application rate may exceed the degradation capacity of the soil and should be avoided.

Herbicides applied earlier in the season have more time to degrade, and this practice will decrease carryover if there is sufficient moisture during the growing season. However, a potential problem with very early (early preplant) application is a greater risk for deep leaching (and possible groundwater contamination) because soils are cooler (slow degradation), evapotranspiration is low, and, in many areas, high rainfall is likely.

Reduced tillage can increase or decrease herbicide residual activity and carry-over, depending on soil properties, the amount of crop residue on the soil surface, and the amount of moisture during the growing season. Lack of soil disturbance will cause an accumulation of organic matter on the soil surface and consequently increase herbicide retention. If the soil is coarse-textured, this may reduce availability after application and increase persistence from that of tilled soil. If the growing season is dry, the higher moisture of the soil with reduced tillage will favor degradation; however, lower soil temperatures under crop residue may decrease degradation during the spring. The higher application rates sometimes required in reduced tillage systems because of interception by crop residue and the accumulation of organic matter on the soil surface may also increase carryover.

Care should be taken during herbicide application to minimize overlap that will result in an excessive dose. This is particularly critical for persistent herbicides and may result in "hot spots" of carryover injury in a rotational crop. Soil properties should be periodically monitored and application rates should be adjusted where possible, based on variations in soil organic matter and pH levels across a field.

PREDICTING RESIDUAL ACTIVITY

The soil is a complex and variable environment, and it is difficult to accurately predict the soil behavior of any herbicide. It is possible, however, to estimate the relative residual activity of a herbicide and its potential for carryover, based on herbicide and soil properties and knowledge of the climatic conditions at a particular location. Management practices can be adjusted to maximize residual activity for weed control and to minimize carryover. *Conservative use of unfamiliar or new herbicides is advisable until sufficient information and experience are gained to adequately predict soil behavior.*

Environmental Effects on Herbicide Performance and Residual

M. Owen

INTRODUCTION

Weed control is the major component of profitable crop production. The use of herbicides is the primary method of weed control. Recent drought conditions during the early spring growing season have resulted in poor weed control and bring into focus the importance of environmental factors on herbicide activity. Further, the relative rate of herbicide decomposition in the soil is also affected by the environmental conditions. The general lack of rainfall has resulted in the failure of some herbicides to degrade to levels that would not impair the growth of rotational crops. This paper will discuss how environmental factors impact on the performance of herbicides, particularly postemergence herbicides, and what likely herbicide residue problems may result from environmental conditions.

ENVIRONMENTAL CONDITIONS AND HERBICIDE PERFORMANCE

The environmental conditions that affect herbicide performance are primarily soil moisture, temperature, and sunlight. Other factors such as relative humidity and wind also have an impact on how herbicides perform; however, these are relatively less important. These conditions affect herbicide performance directly by impacting the herbicide but also indirectly by affecting weed development. Generally, direct environmental effects are the most important for herbicides applied to the soil. Indirect effects are important for herbicides applied postemergence to weeds.

Soil-applied herbicides must be available to germinating weeds for their effective control. Soil moisture is an important environmental condition and largely determines the relative amount of a herbicide adsorbed to the soil. Generally, when a herbicide is adsorbed to the soil, weed control will be lessened. Further, the stronger the herbicide is bound, the greater the problems. Herbicides applied to dry soil will adsorb strongly to the organic and clay colloids which make up Midwest soils. The longer the soil remains dry, the greater the amount of herbicide that is adsorbed and the stronger the adsorptive binding.

Unfortunately, although herbicides may not be available for weed control due to soil moisture conditions, there is generally enough soil moisture for weed seed germination. Thus, weed control can be a major concern if a timely rainfall does not occur soon after herbicide application. Although many herbicide labels suggest that mechanical weed control techniques should be used if rain does not occur within 7 to 10 days after application, the timing should reflect other factors. These factors include soil moisture conditions, the timing of the last tillage operation, and the relative solubility of the herbicide. If soils are relatively dry, mechanical weed control should be accomplished soon after application if a rain does not occur. Similarly, the greater the period between the last tillage and herbicide application, the sooner after herbicide application the mechanical weed control should be done. Last, if a herbicide is relatively insoluble in water, mechanical weed control techniques become more important if rain does not occur soon after herbicide application.

Herbicides that are applied postemergence for weed control are also affected directly and indirectly by environmental conditions. The indirect effects are likely the most significant because of the importance of weed development and the application of the herbicide directly to the weed. Research conducted at Iowa State University has demonstrated dramatic changes in weed development in response to environmental conditions. Notably, temperature and soil moisture affected the development of velvetleaf (*Abutilon theophrasti* Medic.) and giant foxtail (*Setaria faberi* Herrm.), which subsequently affected the performance of fluazifop-P-butyl, acifluorfen, and bentazon.

When soil moisture was limiting and when air temperatures were low, the amount of wax deposited on the leaf surface (epicuticular wax) increased. Further, the composition of the wax changed. The result of these changes was seen in differential uptake of postemergence herbicides. These differences were also seen when several herbicide additives were added to the herbicides. Depending on the environmental conditions, crop oil concentrate or 28 percent UAN may improve herbicide performance. These differences are probably explained when the composition of the epicuticular wax is investigated.

Generally, environmental conditions that increased the amount of polar constituents in the epicuticular wax influenced polar herbicide additives to improve herbicide uptake. Crop oil concentrate was the polar herbicide additive investigated. Conversely, when environmental conditions resulted in a greater amount of nonpolar components, a nonpolar herbicide additive such as 28 percent UAN was more effective in improving herbicide uptake. Soybeans (*Glycine max* L.) did not consistently respond to changing environmental conditions.

While the change in chemical constituents and amount of the epicuticular wax serves to explain the response of herbicides and herbicide additives, significant changes in leaf morphology were also noted. The "architecture" of the leaf epicuticular wax changed in response to environmental conditions and likely impacts herbicide uptake. However, the manner in which epicuticular wax affects herbicide uptake and how herbicide additives interact to influence herbicide activity is not well understood. Research is continuing in this area.

ENVIRONMENTAL CONDITIONS AND HERBICIDE DEGRADATION

The same environmental conditions which affect herbicides applied to the soil also affect how these herbicides degrade. Generally, any environmental conditions which potentially reduce herbicide activity will also slow herbicide breakdown. Several herbicide labels suggest a minimum rainfall requirement for normal herbicide decomposition. However, the timing of the rainfall relative to herbicide application is potentially more important. The relative strength of herbicide adsorption to soils is determined by the soil moisture and length of the rainfree period. Thus, the drier the soil and the longer the soil remains dry, the stronger the herbicide/soil binding and the slower the herbicide decomposition will be. Consequently, rainfall during the first 6 to 8 weeks after herbicide application is probably the most important factor for the timely decomposition of herbicide residues in the soil.

The method of herbicide degradation also reflects the impact of the environment. There are two general methods by which herbicides are degraded, by microorganisms and by chemical reaction. These methods are influenced by environmental conditions in a similar manner that crops are affected. If conditions are favorable for crop growth, herbicide degradation by microbial and chemical activity will be enhanced. However, the optimum levels for the two degradative methods are different. Microbial decomposition of herbicides is favored when soil temperatures are between 60^{o} to 85^{o}F. Chemical degradation of herbicides will continue above the temperatures that are optimum for microbial degradation, and the speed of the reaction will continue to increase with increasing temperatures.

Soil moisture is also an important consideration for herbicide degradation, regardless of the method. Microbial activity is dependent on adequate soil moisture. When soil moisture is limiting, microbial growth and herbicide degradation are slowed. Similarly, chemical degradation has a moisture dependency; the relative importance of soil moisture on the chemical degradation of herbicides depends on the herbicide. Atrazine requires favorable soil moisture for chemical degradation, while recent research suggests that chlorimuron degradation by chemical reaction is less dependent on soil moisture.

There are several herbicides which potentially have had degradation slowed by environmental conditions. These are atrazine (AAtrex), chlorimuron (Preview and Lorox Plus), clomazone (Command), imazaquin (Scepter, Squadron, and Tri-Scept), pendimethalin (Prowl), and trifluralin (Treflan). The severity of the carryover potential depends on the rate and time of application, tillage operations, and localized environmental conditions. The mechanism by which the herbicide affects plant growth and the relative sensitivity of crops that follow also are important considerations. Finally, the environmental conditions during the next growing season will ultimately determine the carryover response of the rotational crop.

Data collected at Iowa State University in late September suggest that approximately 30 to 35 percent of the application rates for atrazine and trifluralin were still in the soil. This amount will not change before next spring. Other herbicides may have greater amounts still in the soil. Herbicide degradation during the fall of 1988 was probably not a major factor. Thus, the potential for herbicide carryover in 1989 is good.

The relative severity of the rotational crop response is dependent on crop sensitivity to the herbicide and the growing conditions. Any environmental condition that stresses the crop will reduce the ability of the crop to tolerate herbicide residues. Corn demonstrates good tolerance to pendimethalin and trifluralin. Iowa State University research has demonstrated that 4x rates of trifluralin do not reduce potential corn yields unless the corn is planted without tillage. Corn also has some tolerance to clomazone. Although the injury symptoms are easily seen, the response is usually temporary and yield reduction is rare.

Soybeans have some tolerance to atrazine. The response will be dependent on the rate of application and timing of application. The atrazine label suggests that late applications will likely cause a carryover problem. Triazine injury to soybeans also depends on the soil pH; the higher the pH, the slower the degradation of atrazine and, thus, the greater the carryover response. Last, metribuzin (Lexone and Sencor) are also triazine herbicides. Application of metribuzin can potentially add to the injury from atrazine residues.

Corn has little tolerance to chlorimuron or imazaquin. However, the likelihood of carryover for these two herbicides is different. Chlorimuron degrades chemically and is degraded by soil microbes. Data from DuPont suggest that even if microbial decomposition is slowed due to unfavorable environmental conditions, chemical decomposition will still occur at a rate sufficient to remove chlorimuron residues before the rotational crop is planted. This will reflect the rate of application; if overlaps occur during application, there still may be sufficient residues to cause a rotational crop response. Further, if the pH is above 6.8, the relative rate of chlorimuron degradation will be slowed and residue carryover may occur.

Imazaquin reportedly degrades primarily by microbial activity. Thus, the potential for carryover in 1989 is good in areas where soil moisture was limiting. Research conducted at Iowa State University investigated the effect of tillage, rate, and timing of application on imazaquin residue. Data were not available at the time of writing, but there were general indications that the yield response was greatest where imazaquin was incorporated and corn was planted without tillage. A corn bioassay was also developed at Iowa State University to determine imazaquin residue levels. The bioassay can detect significant differences at 5 to 8 parts per billion (ppb) imazaquin. The rate of application is generally considered to be approximately 125 ppb. Unfortunately, interpretation of the bioassay and the correlation with actual yield response is difficult. Therefore, Iowa State University does not recommend a bioassay for determining imazaquin residues.

CONCLUSION

Environmental conditions affect herbicide performance and herbicide degradation. Postemergence herbicide activity is primarily affected by soil moisture and temperature. Research suggests that growers may ultimately be able to "design" herbicide treatments that will be minimally affected by environmental conditions. Herbicide degradation is directly impacted by soil moisture and soil temperature. Environmental conditions were not favorable for herbicide degradation during the 1988 growing season. Thus, rotational crop injury is anticipated; the severity of the response and the number of acres affected will depend on the environmental conditions during the 1989 growing season.

Detecting Herbicide Residues and Interpreting Results

B. Curran

Herbicides vary in their potential to persist in soil. Those herbicides that can persist to the next season may injure sensitive rotational crops and need to be monitored more closely. Several methods exist that may be used to detect herbicide residues in soil. These include the chemical analysis performed by commercial laboratories; the bioassay conducted in the suspect field or indoors; and a third technique that is relatively new, the immunoassay. The chemical analysis and bioassay are widely available and will be addressed in this paper. For a more detailed description of testing procedures, please refer to Agronomy Facts W-47, *Testing for Herbicide Residues*.

With the chemical analysis or indoor bioassay, proper sampling of the soil is the critical step. Both tests are only as accurate as the soil sampling technique. Enough samples must be taken to avoid missing locations with higher herbicide residue content. Separate samples should be taken from areas where excessive residues are suspected, such as sprayer turnaround points and end rows. With the field bioassay, it is equally important to plant a bioassay strip through an area where herbicide residue content might be greatest. Plant the bioassay strip in several locations if possible, and include an area that was not treated with the herbicide to serve as a check area.

BIOASSAY

The bioassay will not provide an exact measure of the amount of herbicide residue present in the soil, but it may indicate whether enough residue is present to harm a sensitive crop. The procedure for conducting an indoor bioassay will differ slightly, depending on the herbicide residue of concern.

When the soil has been collected, the next step is choosing a bioassay species. The intended rotational crop is always a good choice. In addition, including a species that is more sensitive to the herbicide residue of concern may prove helpful. If more than one species is grown, the amount of herbicide residue present can be better predicted by observing how the different plants respond. For example, if atrazine residues are of concern, oats and soybean would be appropriate indicator species. The oats are more sensitive to atrazine than soybean, so if the oats show injury and the soybean do not, rotating to soybean is still a possibility. If the soybean are injured along with the oats, a more tolerant crop than soybean would be suggested.

When the bioassay species are chosen, it is important to know what injury symptoms to look for. Injury symptoms will depend on the mode of action of the herbicide. For example, if the herbicide is a photosynthetic inhibitor like atrazine, injury symptoms will first appear in the leaves. Leaf tissue is where photosynthesis actively takes place. With atrazine injury, the leaves appear chlorotic and necrotic starting at the leaf tips and margins. If the herbicide stops cell division as trifluralin (Treflan) does, it is called a meristematic inhibitor and injury symptoms will first appear in areas of active cell division. With trifluralin, the root tips or meristems are affected first, so the roots may appear swollen and growth-inhibited.

CHEMICAL ANALYSIS

Chemical analysis involves extracting the herbicide residue from the soil with various solvents and then detecting very small amounts of the herbicide with specialized equipment. Laboratories differ in what they can test for and how much it will cost. The cost can range from $20.00 to $200.00 per sample. The older herbicides such as atrazine and trifluralin are easier to assay and therefore usually less expensive, while newer products such as Scepter require more elaborate extraction and detection equipment. In addition, cost is generally based on a per-sample analysis, so more samples mean a greater total cost.

Laboratories will report the amount of herbicide residue extracted in parts of herbicide per million parts of soil (ppm). You can transpose ppm into pounds of herbicide per acre (lb/A), using the assumption that an acre of soil weighs 1 million pounds in the top 3 inches and 2 million pounds in the top 6 inches. If we make these assumptions, then 1 ppm equals 1 lb/A of residue for a 3-inch sample and 2 lb/A of residue for a 6-inch sample. A laboratory report of 0.2 ppm atrazine is equivalent to 0.2 lb/A if the samples were taken to a 3-inch depth and 0.4 lb/A if they were taken to a 6-inch depth. Therefore, the depth that we sample becomes very important.

Whether we use ppm or lb/A, translating this into potential injury is very difficult. Many variables affect crop susceptibility or tolerance; they include soil type, soil pH, crop variety, and environmental conditions after planting. Refer to Agronomy Facts W-47 for general guidelines on "safe" residue levels.

In summary, a bioassay or chemical analysis is not 100 percent accurate in predicting herbicide residue problems. Crop response to herbicide residues depends on a number of different factors. However, both the bioassay and chemical test can be helpful tools in deciding whether a potential problem exists and in choosing the appropriate crop or variety.

Avoiding Herbicide Carryover Problems

E. Knake

You like to have herbicides last long enough to provide season-long weed control; but you like to have them dissipate sufficiently so they do not significantly affect the next crop.

The persistence of herbicides varies considerably, and there are many factors that affect persistence. Among these are moisture, temperature, soil microorganisms, soil texture, organic matter, characteristics of soil colloids, chemical reactions in the soil, pH, time of application, and the amount of herbicide applied. Most of these factors are not constant but are part of a dynamic and ever-changing system. Therefore, it is often difficult to predict very precisely the persistence of a herbicide and its degree of risk. However, we do know that the persistence of some herbicides is of relatively short duration and presents little risk to subsequent crops. Others present sufficient risk that they preclude planting of certain crops the next season. Some may or may not affect the next crop, depending on the factors indicated above.

Two of the major factors affecting herbicide persistence are moisture and temperature. Microorganisms that degrade herbicides and chemical reactions for degradation proceed most rapidly under favorable moisture and temperature conditions. During dry periods, herbicides generally persist longer. Thus, there is greater concern about herbicide persistence and possible effect on subsequent crops during dry periods.

If you are concerned about the possibility of herbicides persisting to affect the next crop, there are several things you can do.

1. *Make a bioassay or obtain a laboratory analysis.* A bioassay can be easy, low-cost, and quite meaningful. A field bioassay can be made by simply planting seed of the crop you intend to plant. This might be done in the fall or perhaps in early spring a few weeks before you intend to plant the field. Planting two or three different kinds of seed of differing tolerance can be helpful. When conditions aren't favorable in the field, the bioassay can be made indoors using representative soil samples. Also include soil known to be free of herbicide for comparison. A laboratory test can indicate the amount of herbicide in the soil, but you will also need an interpretation of the test to determine the potential effect of that level on crop plants.

2. *Plant corn after set-aside, small grain, and forages.* Most farmers have used little or no herbicide on these areas, or most of the ones used for these areas present relatively little risk to subsequent crops. There are a few exceptions. If you are mainly concerned about soybean herbicides carrying over to corn, give preference to corn after set-aside, small grain, and forages.

3. *Use suspect fields for set-aside.* If tests suggest possible problems, use as much of the field as possible for set-aside. You may not get a good stand of oats or legume either, but you may be able to have at least a partial stand of some type of cover.

4. *Use herbicides for corn that would allow replanting to soybeans if necessary.* Herbicides such as Lasso or Dual fit this category--possibly Sutan+ and Eradicane and maybe Genate Plus--depending on labeling. If corn injury is excessive, you can replant to soybeans. If corn does make good growth, you can follow with postemergence herbicides to round out your weed control program. There are plenty of postemergence options such as atrazine, Bladex, 2,4-D, Banvel, Marksman, Buctril, and Basagran or Laddok.

5. *Use tillage to dilute the herbicide by mixing it with more soil.* But don't waste fuel needlessly or risk losing soil by using excessive tillage. Aim for uniform mixing to avoid hot spots.

6. *Use cover crops to help degrade herbicides.* When plants--either sensitive or tolerant--absorb herbicide from the soil, they generally degrade it. Thus, winter cover crops or cover crops on set-aside acres can reduce the amount of herbicide residue. Cover crops can also conserve soil. They may reduce soil moisture; that could be good in a wet year but bad in a dry year.

7. *Plant suspect fields last.* That gives more time for herbicide degradation. But don't needlessly risk yield reductions from late planting.

8. *Select tolerant hybrids and varieties.* There are significant genetic differences in the ability of corn hybrids and varieties of other crops to tolerate certain herbicides. Unfortunately, this information may not be readily available. Some information does exist, however, within certain seed firms and chemical companies. Be persistent in trying to obtain it. Consider telling the salesperson that you want a hybrid tolerant of a certain herbicide and let him or her take it from there.

9. *Consider corn after corn and soybeans after soybeans.* But also consider the advantages of rotating crops. In serious situations, the advantage of planting the same crop the next year may outweigh other disadvantages.

10. *Adjust pH.* Some herbicides such as triazines and chlorimuron can be more active and persist longer with high soil pH. Lowering pH may help alleviate a problem, but this may be easier said than done.

11. *Maintain good soil tilth.* When soil is compact and root development is restricted to the herbicide zone, adverse effects may be accentuated. Strive for good tilth that allows roots to rapidly develop and explore soil likely to have less herbicide.

12. *Go easy on the triazines.* Simazine is more persistent than atrazine while Bladex is less persistent. Uniform and accurate application of herbicides containing metribuzin is important, especially following atrazine and a dry season. If you used a reduced rate of atrazine and applied relatively early, you have less to worry about. Although additive effects of atrazine and metribuzin are a consideration, you should also weigh risks of other options.

13. *Follow label recrop times.* Many labels indicate the period of time that should elapse between application and planting of other crops. Under adverse conditions such as drought, additional time may be advisable.

14. *Hope for a late fall and an early spring* to give more time for herbicide degradation.

15. *If you think a rain dance will help, try one.*

FOR THE FUTURE

1. *"Be not the first by whom the new is tried,* nor yet the last to set the old aside." History has repeated itself many times. Herbicide manufacturers and universities do considerable testing of new herbicides before they are introduced in the market. However, when they are used in a wide variety of ways under many different conditions, problems that were not anticipated often arise. When trying a new herbicide, do so on a limited basis for at least a year or two until the herbicide proves itself. Frequently, potential problems are anticipated, but their magnitude cannot always be predicted.

2. *Use the right rate.* With many herbicides, the margin for error is quite narrow; use enough to obtain good weed control but not more than the present or subsequent crops can tolerate. An extra "glug from the jug" may improve weed control, but it may cause crop injury.

3. *Apply accurately.* Be sure the herbicides are applied accurately and uniformly. Overlaps, double dosing on field ends, excessive amounts on fields with odd shapes, or slowing down the sprayer can lead to problems.

4. *Incorporate uniformly.* Surface applications can mean more uniform distribution, less risk of hot spots and crop injury, and fewer skips and streaks for weed control. Incorporation, however, can mean less dependence on rainfall and better weed control. Especially for herbicides with close crop tolerance, uniform distribution can be extremely important. Use equipment that will mix the herbicide uniformly. A second pass is generally well worthwhile for many herbicides.

5. *Avoid adverse combination additive effects.* Herbicide combinations can broaden the spectrum of weed control, and some combinations may reduce risk of injury to the present or subsequent crops. However, some premixed or tank mix combinations or sequential applications may increase risk of crop injury. Design combinations carefully to avoid adverse additive effects from herbicides with similar action or when each has relatively long persistence.

6. *Use "shorter" herbicides.* Give preference to herbicides and herbicide combinations that will last long enough for good weed control, but will probably not persist long enough to adversely affect the next crop. Use lower rates in appropriate combinations. Review cropping restrictions before you use a herbicide and be sure it meshes with your cropping sequence.

7. *Apply early.* Using soil-applied herbicides early will give more time for degradation before the next crop. For postemergence herbicides, select optimum rates and lean toward early application. That can give better weed control and reduce risk of residual carryover.

8. *Change your mind.* They say that "We learn from the mistakes of other people, but some of us are the other people." As you gain experience with new compounds, fine-tune your herbicide program. Adjust rates. Modify combination ratios. Change time of application. Improve accuracy and uniformity. But don't change too quickly from a relatively successful program just to try something new.

Many herbicides have been introduced. Some have fallen by the wayside. However, many have found a place as their use has been modified to gain the greatest benefit while minimizing problems.

New Methods for Herbicide Detection

F. Koppatschek

Are you concerned about herbicide carryover? The need to detect herbicide residues is at an all-time high. An innovative approach to detecting herbicide residues is the use of immunoassay.

An immunoassay is based on the principle that animal systems can produce a specific antibody to a foreign substance. When herbicides are introduced into a test animal, usually a rabbit, the animal's immune system recognizes the herbicide as a foreign substance and produces an antibody. Serum that contains the antibody is collected from the animal. This antibody can be used to assay for the herbicide.

The immunoassay has several advantages and disadvantages over present forms of residue detection. The primary advantage of the immunoassay is speed of detection. On an average day, 40 to 50 herbicide immunoassays can be performed. Using conventional high-performance liquid chromatography (HPLC) or gas chromatography (GC) methods, six to eight assays can be performed per day. Bioassays take several weeks to complete. The cost of immunoassay can also be lower than traditional methods of detection. A potential problem with immunoassay is trying to obtain a consistent supply of antibodies. Cross reactivity with other compounds in the soil can also limit the detection accuracy of immunoassay.

At the University of Illinois, we are developing immunoassays for clomazone (Command) and imazaquin (Scepter). Our clomazone immunoassay can detect 10 parts per billion (ppb) of clomazone with excellent specificity. At the present time, our imazaquin immunoassay is in early stages of development. There are several commercially available immunoassays. Immunoassays for atrazine, 2,4-D, paraquat, and several other herbicides are presently available in kit form.

We are excited about the potential of immunoassays for simplifying herbicide detection. Immunoassays may play an important role in herbicide detection and can help in making agronomic decision making easier.

The Impact of Charcoal Rot of Soybeans on the 1988 Crop

D. Eastburn

Those soybean growers who survived Rhizoctonia seedling blight, the drought, soybean mosaic virus, and spider mites still had one more hurdle to overcome, and that was charcoal rot. Very few diseases were evident in this summer, which was marked by little rainfall and higher than normal temperatures; charcoal rot was an exception. The disease, caused by the fungus *Macrophomina phaseolina*, is favored by hot, dry weather, especially in combination with unfertile soil or other unfavorable growing conditions.

Though the fungus can cause a seedling blight, charcoal rot usually appears after midseason, shortly after flowering, and tends to be more prevalent in the southern half of the state. The symptoms this summer were somewhat masked by all the other problems, but much of the premature senescence attributed to the drought or spider mites was, in fact, a result of charcoal rot. The disease was evident as early as mid-June in some parts of southern Illinois.

The first symptom of charcoal rot is the development of a silvery discoloration of the epidermis on the taproot and lower stem. If the epidermis is scraped or peeled back, numerous small black specks (microsclerotia) can be seen in the tissue as a grayish black color, hence, the name charcoal rot. If the root and lower stem are split open, a reddish brown discoloration of the vascular tissue, which starts in the taproot and gradually moves up into the vascular tissue and pith of the lower stem, can be seen. In an advanced stage, wavy black streaks appear in the woody portion of the lower stem. Infected plants usually produce smaller than normal leaves; and as the disease progresses, the leaves turn yellow, then wither and turn brown, but they usually remain attached to the plant for some time (one way to distinguish charcoal rot from normal plant senescence).

The fungus infects through the feeder roots where it moves into the xylem and progresses toward the taproot and then up into the plant. The feeder roots are killed. As a result, the plants in advanced stages are easily pulled out of the ground. Once in the vascular tissue, the fungus produces microsclerotia that plug the vessels and inhibit water flow. Symptoms are thought to result from vascular plugging, a toxin produced by the fungus, mechanical pressure, or a combination of these factors. Symptom development is favored by dry soil and temperatures between 85^{o} and $95^{o}F$ (28^{o} and $35^{o}C$).

The microsclerotia are the means by which the fungus survives from season to season in the soil. *Macrophomina phaseolina* is a poor competitor in soil, and populations can only increase in the presence of a susceptible host, which is why the disease becomes more severe in successive crops and is most severe where soybeans have followed soybeans. The fungus, however, can attack and reproduce on a wide range of crop plants, including corn and sorghum where it causes a stalk rot. Survival of the microsclerotia is favored by dry soil conditions. Under wet conditions, the sclerotia lose viability in a matter of 7 to 8 weeks.

Yield losses result from poor pod fill, with infected plants often producing one or two small beans per pod. These beans will often be shriveled and green. The disease can hit scattered plants or large patches in a field. Yield losses for this past season have been estimated at between 8 percent (central Illinois) and 30 percent (southern Illinois), but it is difficult to isolate the losses caused by charcoal rot from other yield-reducing factors.

There are no charcoal rot-resistant soybean varieties and no means of chemical control. Control is based primarily on cultural practices.

1. Avoid dense stands by using lower seeding rates.
2. Fertilize to encourage vigorous growth.
3. Irrigate where possible.
4. Plant full-season varieties as early as possible.
5. Practice crop rotation with cereals or other nonhost crops.
6. Maintain a good weed control program.
7. There is some evidence that infection by the soybean cyst nematode (SCN) increases root colonization by *Macrophomina phaseolina*, so planting SCN-resistant varieties where SCN is a problem may help to reduce the level of charcoal rot.

Because of the high levels of disease this past season, the inoculum level for 1989 will be higher than normal. Disease levels, however, will depend more on climatic conditions than on inoculum level. If we have lower summer temperatures with normal or above-normal rainfall, charcoal rot will probably not be much of a problem. On the other hand, if 1989 is anything like 1988, charcoal rot will once again cause significant yield losses.

The Spider Mite Outbreak of 1988: Did We Learn Enough to Improve Our Decision-Making Capabilities?

M. Gray, G. Pepper, and J. Fredericks

In 1983, an estimated 2.2 million acres of soybeans were treated in Illinois for the twospotted spider mite, *Tetranychus urticae*. Central and southern counties of the state had the most severe infestations. During 1988, it has been estimated that 6 million acres of soybeans received an insecticide application to reduce spider mite populations. What common thread wove these two severe mite outbreaks together?

Historically, prolonged hot and dry conditions have precipitated spider mite injury to crops. Both 1983 and 1988 will be remembered for the very dry conditions that prevailed during a portion of each summer. In 1983, most soybean fields that eventually became infested began showing symptoms of spider mite damage during the third week of July through the first week of August. Conditions were drier much earlier in 1988, and reports of spider mites destroying clover fields were common during early June. The suddenness and severity of early mite injury took many producers by surprise, especially those who had experienced spider mite damage to their soybeans in the latter portion of the summer in 1983. Because of the early development of mite populations and the prolonged drought in 1988, farmers were continually plagued by reinfestations of spider mites into fields that had been treated earlier in the summer. In 1983, rains fell during the early part of August and populations of mites began to decline in many affected areas of Illinois.

Each of the most recent episodes of spider mite outbreaks had some similarities and differences. Perhaps by looking closely at each year we can attempt to answer some of the following questions. What causes spider mite populations to increase to damaging levels? Did we manage spider mite populations similarly in 1983 and 1988? Can we more clearly define economic thresholds for spider mite populations? If an outbreak occurs again, have we learned enough to make better management decisions? These questions will serve to guide this discussion.

WHAT CAUSES SPIDER MITE OUTBREAKS?

Many physical and environmental factors interact to influence the likelihood of a spider mite outbreak. Identifying a single factor as solely responsible for a population explosion of mites is too simplistic. Huffaker et al. (1970) listed the following elements that contribute to spider mite dynamics: (1) features of the life cycle (Figure 1), particularly with regard to movement phases and potentials, reproduction, and diapause; (2) meteorological conditions, including photoperiod effects; (3) the nutrition afforded by the host plant and its relative susceptibility or resistance to the mites; and (4) action of enemies, particularly predators. In addition to these components, the manner in which spider mite populations are managed when they reach potentially damaging levels may also play a crucial role in the success of insecticide/miticide applications.

Is there a direct link between hot, dry weather and an increase in populations of spider mites? The evidence is not as clear as it might seem. Simpson and Connell (1973) examined rainfall data over a 7-year period in Delaware and found that total summer precipitation could explain 51.3 percent of the population variation of the spider mite *Tetranychus turkestani* in soybean fields. They reported, "The periods of the low infestations were preceded by a substantial amount of rainfall, while the more severe infestations were preceded by less-than-normal rainfall." Populations of any organism are influenced by an array of biotic and abiotic factors and their subsequent interaction. The results of Simpson and Connell (1973) indicate that rainfall may be an extremely important limiting factor in spider mite population dynamics.

An experiment conducted by Hollingsworth and Berry (1982) revealed that densities of twospotted spider mites, *Tetranychus urticae*, increased more rapidly on peppermint plants that were under moisture stress than on nonstressed plants. The investigation was conducted in an environmental chamber. Another component of their study focused on the impact of cultural practices on mite population dynamics. Fall plowing of experimental peppermint plots in southwestern and central Oregon delayed the onset of spider mite infestations the following season by approximately 1 month. They speculated that plowing may have inflicted direct mortality on mite populations in the soil through abrasion or burial of mites. They concluded that by delaying the onset of critical densities of spider mites the following season, the number of chemical treatments required could be reduced. Although fall plowing may work very well as a pest management tactic in some arid regions of Oregon, it should not be recommended for areas of the country where soil erosion is of much concern or where mite populations are of only occasional economic importance.

Mellors and Propts (1983) examined the impact of fertilizer level, fertility balance, and moisture stress on densities of the twospotted spider mite *T. urticae* Koch on radish plants grown under greenhouse conditions. Low soil moistures resulted in smaller plants and lower total mite populations. No significant impact on the mite intensity (number of mites per gram of foliage) was observed at either watering regimen. The greatest intensities of mites were observed on plants that had been fertilized with a high ratio of N to P and K. The researchers also reported that the largest populations of spider mites were associated with plants grown at higher air temperatures. This observation supports the earlier hypothesis of Simpson and Connell (1973) that high temperatures may be important for mite population expansion.

In another greenhouse investigation, Mellors et al. (1984) looked at the effect of water stress on the growth of soybean plants and twospotted spider mite *T. urticae* Koch populations. Significantly more spider mites per plant were observed on soybeans given the high versus the low watering rate. Spider mite intensities (mites per gram of blade) in the two moisture level treatments were not statistically different. They were, however, two- to threefold greater on plants receiving the high watering rate. They concluded, ". . . moisture stress reduced both soybean plant and total spider mite population growth and apparently also reduced intensity." This pattern is similar to the trend observed with twospotted spider mites on radish plants (Mellors and Propts 1983), but it disagrees with the research of Hollingsworth and Berry (1982) involving peppermint.

In a recent greenhouse investigation, Oloumi-Sadeghi et al. (in press) evaluated the influence of water stress on the abundance of twospotted spider mites on soybeans. They found significantly fewer eggs and female mites per cm^2 on plants that were under severe moisture stess. The levels of immature and male spider mites did not differ significantly among plants under differing water stresses. Based upon their research and that of Mellors et al. (1984), they suggested that outbreaks of twospotted spider mite populations during drought years should not be attributed exclusively to changing physiological parameters within the plant associated with moisture stress.

Clearly the results from these investigations differ with respect to the influence that moisture-stressed plants have on spider mite population dynamics. It is important to recognize that much of the research conducted on this subject has been carried out under greenhouse conditions. The array of biotic and abiotic factors that occur in the field differ considerably from those in a greenhouse. Therefore, care must be exercised when extrapolating results obtained in a carefully controlled environment to conditions in a soybean field.

Let's return to the original question of this discussion, "What causes spider mite outbreaks?" To attribute a rapid increase in the number of mites during droughts solely to moisture-stressed plants is probably too simplistic. What other factors may contribute to explosions of phytophagous (plant-eating) populations of arthropods during dry periods? Mattson and Haack (1987) discussed several hypotheses that may explain why drought stress tends to promote outbreaks of plant-eating arthropods. They listed the possible outcomes of a drought that could influence insect and plant interactions. Although mites are not insects, we assume that phytophagous mites respond to drought conditions similarly to plant-eating insects, particularly those that have piercing and sucking mouthparts.

1. Drought provides a more favorable thermal environment for growth of phytophagous insects.

2. Drought-stressed plants are behaviorally more attractive or acceptable for insects.

3. Drought-stressed plants are physiologically more suitable for insects.

4. Drought enhances insect detoxification systems to some plant allelochemicals.

5. Drought may not favor natural enemies of phytophagous insects.

6. Drought may induce genetic changes in insects.

To pinpoint any single factor as being responsible for spider mite outbreaks during the summers of 1983 and 1988 is foolhardy. It is probable that an interaction of several mechanisms resulting from drought conditions will cause mite outbreaks in the future.

DID WE MANAGE TWOSPOTTED SPIDER MITE POPULATIONS ANY DIFFERENTLY IN 1988 THAN IN 1983?

Proper management of a population of mites implies that sufficient knowledge is available regarding economic thresholds (ET) and economic injury levels (EIL), which, when utilized, assists in treatment decisions. Stern et al. (1959) proposed the following definitions for EILs and ETs. An EIL is "the lowest pest population density that will cause economic damage"; an ET is "the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level." Knowledge of the general equilibrium position (GEP), or the density of a population over a long period of time, is also necessary. Twospotted spider mites may best be described as occasional pests (Figure 2), that is, their population density only occasionally exceeds the EIL. The use of control measures may be warranted only in certain years, as we observed in 1983 and 1988 in Illinois.

The amount of information needed to establish workable ETs and EILs is quite staggering. Carefully designed sampling strategies are required in order to accurately assess the level of a particular pest on its host plant. Population estimates are often so variable that they tend to be almost useless within the context of a pest management program. In other words, can we say with any certainty that the ET or EIL of spider mites has been reached at a given point in time? In addition to knowledge about the pest population, we need to know whether the host plant can compensate for past injury. Can we equate spider mite injury to foliage with levels of defoliation? Answers to these very tough questions have not been resolved.

Were twospotted spider mite populations in 1983 and 1988 managed in a similar fashion across Illinois? The answer to this question is, most certainly, yes! In the August 19, 1983, issue of the *Insect, Weed & Plant Disease Survey Bulletin* (*IWPDSB* No. 20), the following ET was suggested: "We suggest an insecticide application when symptoms first appear, when mites are present, and when the plants are suffering from moisture stress." During the outbreak in 1988, the recommended ET had not been refined to any significant extent. An attempt was made in 1988 to equate spider mite injury to injury caused by defoliation of chewing insects. The August 5, 1983, *IWPDSB* (No. 18) provided a table (Table 1) to assist producers in estimating potential yield loss as a result of spider mite injury. During both years, spot treatments and spraying of infested border rows were proposed as management strategies to prevent the spread of mites throughout a field. Scouting the entire field for the presence of mites was also strongly encouraged. In some instances, producers ignored the latter recommendation and were forced to eventually treat entire fields, which meant that border rows were sprayed twice.

CAN WE MORE CLEARLY DEFINE ECONOMIC THRESHOLDS FOR SPIDER MITE POPULATIONS?

In 1983 and 1988, some spider mite management decisions were easy to make. When soybeans were under severe moisture stress and the majority of the plants had gross symptoms of injury (leaves with yellow and brown necrotic areas) and numerous spider mites, the choice to use an insecticide was clearcut. In this situation, trying to define an ET in terms of mites per leaf or mites per plant is probably only of academic importance. The chief concern of the producer in this situation is to prevent further economic losses. Carefully defined ETs serve a less critical role in the decision-making process when making the choice not to treat will clearly lead to dead plants.

Treatment recommendations were much more difficult to suggest when the choices were not black or white. For example, should a grower treat his field when the plants are showing only light to moderate levels of mites and very minor symptoms of injury, and the forecast for the next week calls for moderate temperatures and a 50 percent chance for rain? When a question like this was posed to Extension personnel or crop consultants, more clearly defined ETs would have helped considerably. What form of an ET would be practical? Because mites are so small, counting the number of mites per leaf from a given number of plants sampled randomly within a field is too time-consuming for a crop consultant. A visual rating scheme based upon the amount of foliar injury may offer more promise as a workable ET. This tactic calls for estimating the effects, in this case, the damage caused by a population of spider mites. These "population indices" are often used to estimate populations of organisms when counting the animals is impossible or impractical. By utilizing a foliar damage scale on leaves across a soybean field, a much quicker and perhaps more accurate treatment decision might be made. Soybean leaves from an infested field were rated for spider mite injury last summer, and the results offer promise for the continued development of an ET based on a visual damage rating scale.

On August 4, 1988, measurements were taken within a field of Williams 82 soybeans that had variable levels of spider mite injury. Five different areas (20 sq. meters/area) of the field were chosen for study, and each area was representative of the variation in spider mite damage observed across the field. Using a portable LiCor 6000 gas analyzer, we determined net photosynthesis rate, stomatal resistance, and transpiration rate for leaves that remained attached to the plant. All measurements were taken between 11 a.m. and 1 p.m. on a relatively clear day. Leaves used for these analyses were also used for estimates of total chlorophyll content and mite intensity. Infested leaves from each area were selected based on the following visual damage rating scale: (1) leaves normal green, with no apparent mite damage; (2) leaves paler green, some yellow mottling evident; (3) yellow mottling more prevalent, tending to cover leaf surface with a few necrotic areas apparent; and (4) leaf extensively mottled, with numerous necrotic areas. Spider mite intensities were estimated by removing five leaf discs (3.14 cm^2/disc) per trifoliate leaf and examining them under magnification.

We detected significant differences in net photosynthesis, stomatal resistance, transpiration rate, and total chlorophyll content among the different visual leaf damage rating scores. As spider mite injury to leaves increased--reflected by higher leaf rating scores--net photosynthetic capacity decreased, stomatal resistance increased, transpiration rate decreased, and total chlorophyll content decreased (Table 2).

Based upon these preliminary results, we can probably estimate the level of physiological stress a mite-infested soybean plant is undergoing by using a leaf damage rating scale. An examination of the means in Table 2 reveals that the damage scale more clearly correlates with the various physiological parameters measured than the estimation of mite intensity does. Based upon the results of this study, the average level of leaf damage in a field is probably a better method for deciding whether a field should be treated for spider mites than attempting to make mite counts. In our investigation, leaves that were rated 2 to 4 had similar numbers of mites, yet they differed considerably with respect to physiological stress. It seems probable that spider mites had dispersed from the more seriously damaged leaves before the samples were taken.

We also observed a highly significant relationship between photosynthetic rate and leaf injury scale ($n = 20$, $R^2 = 0.75$, $P < 0.01$) (Figure 3). Leaves that were assigned an injury rating of 4 had photosynthetic rates approximately three times less than those with a rating of 1. The maximum levels of photosynthesis measured in this investigation (leaf rating 1) were less than those reported on nonstressed leaves. These data indicate that even low infestations of spider mites on plants that are under moisture stress can cause less than optimum photosynthetic rates. The significant reduction of photosynthetic activity in leaves that were assigned ratings of 3 or 4 was further confirmed in the laboratory when we examined the total chlorophyll content of leaf discs. Leaves that were rated 4 on the damage scale had approximately half as much chlorophyll as leaves assigned a rating of 1. This relationship indicates that contrasts in chlorophyll content of leaves can be visually recognized.

Stomatal resistance was more than twice as great in soybean leaves with a rating of 4 than in leaves rated 1. This highly significant relationship ($n = 20$, $R^2 = 0.75$, $P < 0.01$) is illustrated in Figure 4 where stomatal resistance is regressed upon the damage rating scale. As resistance to gas exchange increases within a leaf, leaf temperatures may begin to increase and photosynthetic rates to decrease. While not unexpected, reduced rates of transpiration were associated with increased stomatal resistance. Transpiration rates were considerably lower in leaves assigned a rating of 4 than in leaves with a rating of 1 (Table 2). Measurements taken on soybean photosynthetic rates indicate that twospotted spider mite damage is associated with a reduction in total chlorophyll content. Spider mite injury to leaves is correspondingly linked to increased resistance to CO_2 entry into the leaf. These preliminary results indicate that visual estimates of leaf damage may be more useful than mite counts in predicting the physiological stresses soybean plants are experiencing.

HAVE WE LEARNED ENOUGH TO MAKE BETTER MANAGEMENT DECISIONS NEXT TIME?

In attempting to understand how biotic and abiotic factors interact in an agroecosystem, there is always more to learn. Accepting this premise, have we learned enough about recent spider mite outbreaks to enhance our decision-making capabilities? A management decision, as discussed earlier, relies on information concerning the ET and EIL of a pest population. These thresholds serve as the trigger (ET) for preventative action to be taken to prevent economic loss (EIL). Despite the most recent research concerning how soybean plants respond physiologically to a spider mite infestation, much more research is necessary before we can confidently recommend a more refined ET.

We have taken some steps toward developing a more workable spider mite ET. Based upon the difficulty and time required to count mites on soybean leaves, it is doubtful that a future ET will rely on mite population estimates. Mite counts in our investigation did not correspond very well to leaf damage estimates. This was, in part, probably due to the dispersal of mites away from severely damaged leaves. Using a leaf damage rating scale seems to offer promise for accurately depicting the level of stress in a mite-infested soybean plant. After spider mites have been identified as the cause for leaf injury, leaves from a cross section of the field could easily be collected and rated, and an average level of damage could be determined. If the damage exceeds an "acceptable" level of stress, the decision to treat can be made. The term "acceptable" would imply a degree of stress not likely to cause a yield reduction. Obviously, more research regarding the impact of long-term reductions in photosynthetic rates upon yield is warranted. Can a soybean field withstand a leaf injury rating of 2 for several weeks under drought conditions? This type of question will continue to challenge entomologists and agronomists.

Management decisions with regard to spider mite infestations will continue to be complex. Although we haven't learned nearly enough to greatly improve our economic thresholds, we have taken a first step in the right direction. Only continued research efforts can test the potential usefulness and reliability of an ET based upon a leaf injury scale.

Table 1. Estimates of Percentage Yield Loss According to Defoliation and Stage of Soybean Development

Percent defoliation	Prebloom	Full bloom	Full pod	Full seed
10	0	0	0	0
20	0	2	3	0
30	0	3	5	3
40	0	5	10	4
50	2	10	15	5
60	3	15	25	9

SOURCE: *Soybean Insects: Identification and Management in Illinois*, Agric. Exper. Sta. Bull. 773, Univ. Illinois, Urbana-Champaign.

Table 2. The Influence of Twospotted Spider Mites on the Physiology of a Soybean Leaf

Damage scale	Net pn[a]	Stomate resistance[b]	Trans[c]	Chloro[d]	Mites[e]
1	19.22	92.6	206.6	1.10	16.79
2	12.84	120.6	175.0	0.82	23.32
3	10.16	141.6	155.4	0.71	22.24
4	5.98	208.2	123.6	0.54	25.48
SE[f]	2.78	24.6	17.4	0.12	1.85

[a]Net pn = net photosynthesis as μmol m^{-2} s^{-1}.
[b]Stomate resistance as sec/m.
[c]Trans = transpiration as mg H_2O m^{-2} s^{-1}.
[d]Chloro = chlorophyll as mg dm^{-2}.
[e]Intensity of mites per 3.14 cm^2 leaf disc.
[f]SE = standard error.

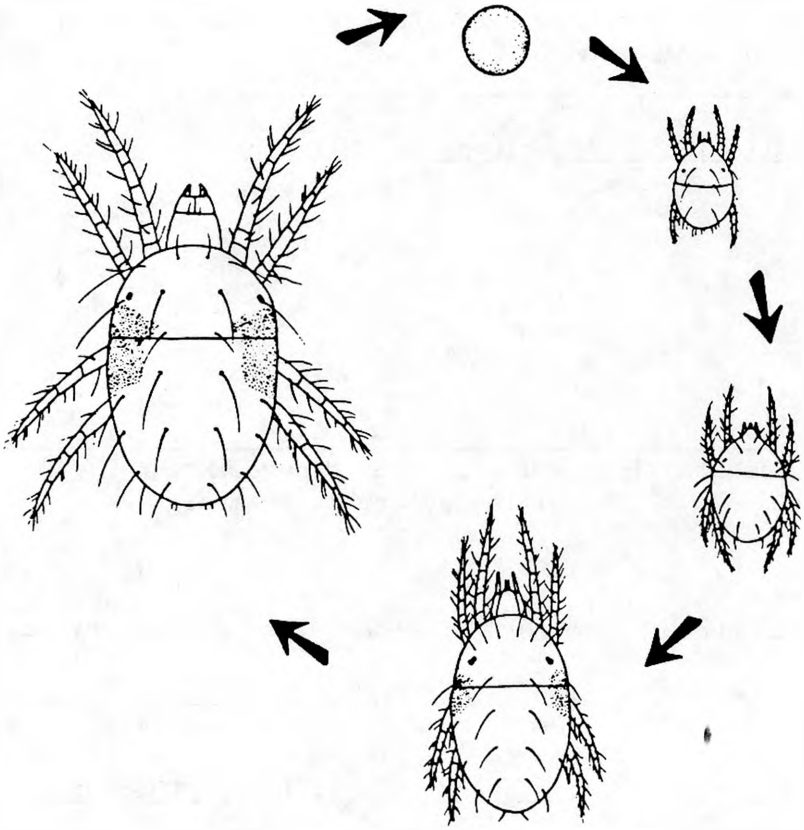

Figure 1. Life cycle of the twospotted spider mite. Egg, larva, protonymph, deutonymph, and adult.

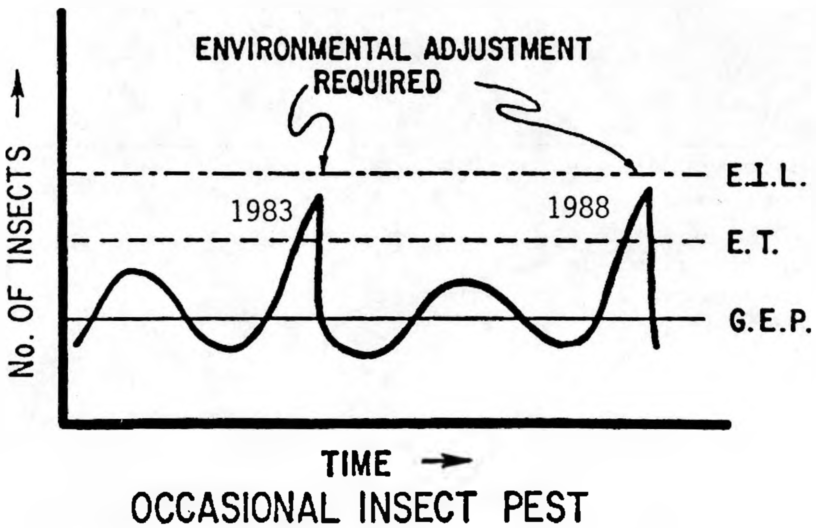

Figure 2. Example of an occasional pest. Years indicate most recent spider mite outbreaks.

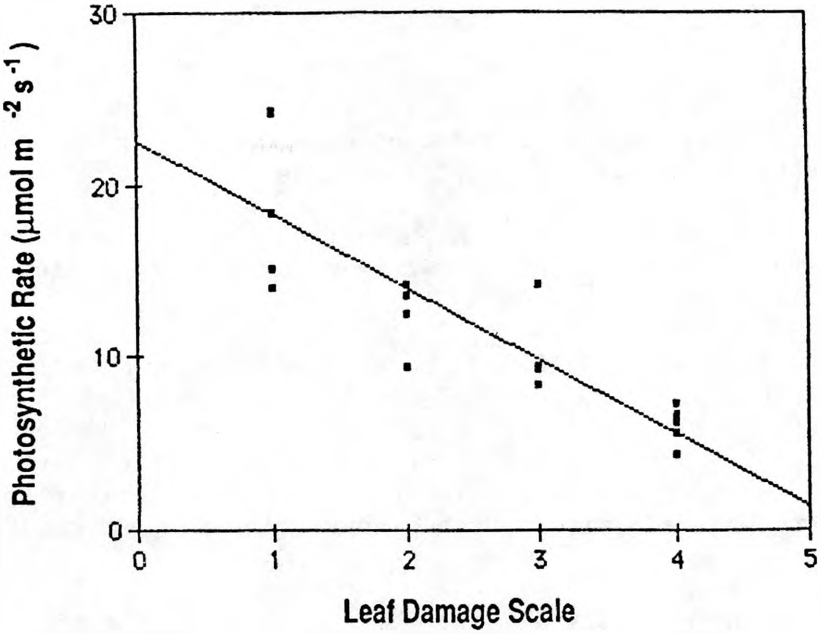

Figure 3. Relationship (regression analysis) of photosynthetic rate and leaf damage scale.

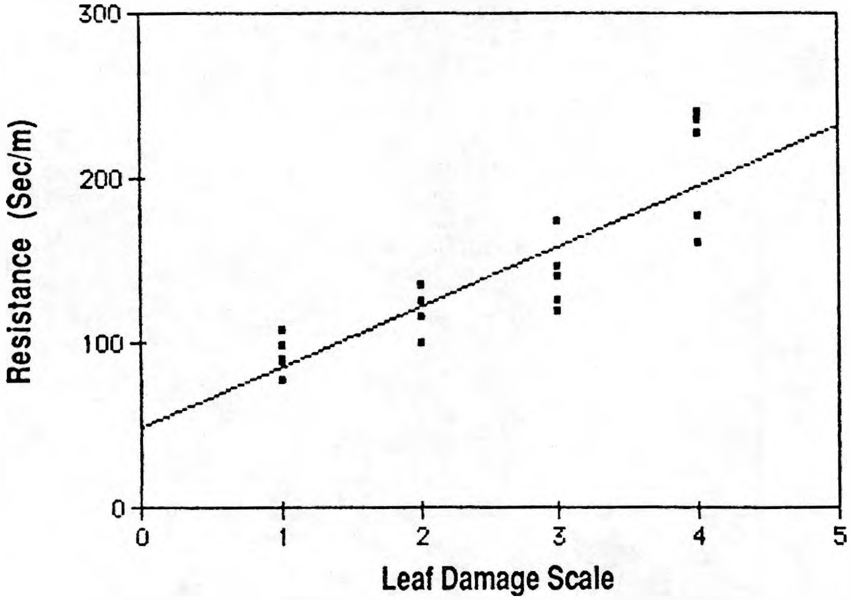

Figure 4. Relationship (regession analysis) of stomatal resistance and leaf damage scale.

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Pesticide Application Mishaps in 1988

B. Anderson

Pesticide mishaps, mistakes, or misapplications are not very positive for the pesticide industry. I am obligated to be more specific and state that the mishaps in 1988 were largely attributed to aerial applications of Cygon, Lorsban, Dimethoate, and other insecticides used to control spider mites in soybeans in Illinois.

Used according to label directions, pesticides are a valuable tool in agriculture. However, the number of complaints received by the Illinois Department of Agriculture (IDA) in 1988 indicates that not all applicators heeded label directions. I fear that our pesticide education program has been set back many years.

How were the insecticides misapplied? Most reported mishaps were related to applications of insecticides to nontarget sites or to drift caused by excessive wind. Following are some examples of the types of complaints that the IDA received in 1988.

One of the earliest complaints involved either drift or off-target spraying of a subdivision in Bolingbrook, Illinois, just south of Chicago. The complaint involved contamination of three swimming pools and nearby areas that were sprayed. Another significant complaint involved spraying at the edge of a hog lot adjacent to a soybean field. The lot contained 500 hogs ready for market. IDA personnel observed that the mud puddles in the lot were milky colored, and the lab found high levels of dimethoate in samples from these puddles. Fortunately, dimethoate is an organophosphate and passes out of animals with the urine after a short while.

Another complaint involved direct spraying of a residence, which caused the occupants to move out of the house for several days. Other mishaps included spraying of gardens, fruit trees laden with fruit, and a milking goat herd, which resulted in dumping of high-priced goat's milk; spotting of vehicles; spraying people and fish ponds (the latter resulted in fish kills); and killing honey bees.

Some applicators have stated that the people who complained were all "kooks." Some were undoubtedly very negative toward pesticides and might have exaggerated their complaints. In fact, two people told me over the phone that they were soaking wet from a spray application. I find this hard to believe, considering an aerial application uses only 2 to 5 gallons of water per acre. Nevertheless, they did not deserve to be sprayed. Another gentleman who operated a large organic garden told me that when an aerial applicator made the second pass, he ran out with his 30/30 rifle but then decided not to use it.

These are only a few examples of the types of complaints we received in 1988. Now I'll explain how these calls are handled by the department. As soon as we receive a call, we mail to the complainant a complaint blank to be filled out and returned. It is a rather lengthy form, so we often get rid of the petty complaints because the complainants do not return the forms.

If the complaint seems valid and possible damage to persons or property has occurred, we assign the case to one of the field staff to investigate as soon as possible. The field investigator interviews the appropriate people, usually takes photographs, and collects residue samples to test for contamination by pesticides. After the investigation is complete and the samples have been analyzed by the lab, the administrative staff reviews the file with the investigator and determines what type of enforcement action, if any, should be taken. The decision then is to close the file if there is no evidence of misuse or misapplication of a pesticide; send an advisory letter informing the applicator to be more careful; send a warning letter; or require the applicator to come in for an administrative hearing. Based on the number of penalty points accumulated under the Illinois Pesticide Act, the applicator could be assessed a penalty ranging from $750 to $10,000. This type of action, of course, is distasteful to all parties involved.

The IDA had approximately 80 cases to consider during the summer of 1988. This is not a large number of complaints, considering millions of acres were sprayed for spider mites. However, I believe that if we don't take measures to reduce the number of complaints in the near future, we might anticipate legislation that would seriously curtail aerial applicators in Illinois. For example, legislation might demand that large buffer zones be established around subdivisions or even individual residences--or, more drastically, aerial applications might be banned.

I realize that millions of acres of soybeans had to be sprayed over a relatively short period of time. As a consequence, applicators became exhausted and were probably not as careful as they could have been. Others believe that the pesticide mishaps were caused by out-of-state applicators. Although this is partially correct, most of those applicators were spraying for a licensed applicator in Illinois, so we still hold the Illinois applicator responsible.

Not all applicators caused problems in 1988. Indeed, some applicators went out of their way to maintain good community relations. I know of one instance in which an applicator was accused of killing honey bees. Although he was not legally liable, he reimbursed the beekeeper for the dead bees.

Other types of problems that the IDA handled in 1988 included applicators spraying without a license and dealers selling restricted-use pesticides to unlicensed applicators. Penalties for these violations are stated clearly in the Illinois Pesticide Act, and these cases resulted in fines from $500 to $5,000.

Most private and commercial applicators in Illinois are properly licensed and do an excellent job, and a few of these occasionally make small mistakes. However, a small minority of applicators create problems for everyone through their abuses of pesticides and pesticide regulations. We hope that the point system and associated fines that are imposed through the Illinois Pesticide Act will help to educate or even eliminate the latter type of applicator in Illinois.

Environmental Factors Influencing Corn Rootworm Biology and Control

G. Sutter and R. Gustin

For at least the past four decades, researchers involved with biological and control studies of corn rootworms, *Diabrotica* spp., have annually observed major shifts in population densities of these pests. Factors regulating their abundance are not thoroughly understood. Numerous publications, dating back to Forbes (1896), have advocated crop rotation as a method to prevent serious larval feeding injury. Forbes also suggested that maintenance of good soil fertility, although it did not control the insect, permitted corn to produce a reasonable crop under light infestations of rootworms. Tate and Bare (1946) summarized control recommendations for the "Colorado" (western corn rootworm ([WCR]) and the northern corn rootworm (NCR) species, *Diabrotica virgifera virgifera* LeConte and *D. barberi* Smith and Lawrence, respectively, and advocated crop rotation--particularly in fields where rootworm damage was common. They also suggested that corn should not be planted in grain stubble in which volunteer corn had been permitted to grow. They listed certain supplementary measures that would aid in reducing losses caused by rootworms: (1) listing rather than surface planting, (2) fall tillage, (3) timely irrigation, and (4) use of hybrids having unusual capacity to recover from root injury. Forty years later, we believe these control recommendations are still valid. Now we have a better understanding of the basis for these recommendations. In this paper, we present data that support the recommendations of Tate and Bare and discuss key environmental factors--specifically, winter soil temperatures and precipitation during egg-hatch and larval feeding, which regulate corn rootworm population dynamics and affect rootworm control.

SOIL TEMPERATURE AND TILLAGE

Gustin (1981) found that when WCR eggs were subjected to soil temperatures of $10^{o}C$ for 3 to 4 weeks, there was a significant increase in egg mortality. During a 4-year study we conducted in the northern Corn Belt, soil temperatures in fall moldboard-plowed plots were below this temperature 2 out of the 4 years. We observed very low populations of WCR in each growing season after a winter during which low soil temperatures were recorded. Gustin found great differences in soil temperatures among tillage systems; moldboard-plowed soils had the lowest winter soil temperatures, and small-grain stubble plots had the warmest soil during these months. He also reported a significant increase in mortality when WCR eggs were subjected to intermittent temperatures of freezing and thawing. Soils without ground cover, for example, snow or crop residue, frequently experience temperature fluctuations of 8^{o} to $10^{o}C$ (Gustin 1986). However, low soil temperatures did not seem to affect the survival rates of NCR eggs as much as they affected WCR eggs (Gustin 1983).

PRECIPITATION

We have observed that soil moisture, particularly during certain times in the rootworm's life cycle and where soil insecticides have been applied, influences

WCR survival rates. We have used the controlled infestation technique (Sutter and Branson 1986) in research plots where soil conditions were monitored during the larval feeding period to measure the effect of soil moisture on pest/host relationships and on insecticide efficacy. Sutter et al. (in press) found during a 5-year study that soil moisture, primarily affected by precipitation patterns during egg-hatch and early larval development, was critical for successful larval establishment on the roots of its host. In untreated plots, larval establishment and feeding damage, estimated by root damage ratings (Hills and Peters 1971), were not influenced by rainfall if it occurred after egg-hatch. Figure 1 reveals the cumulative precipitation during these years. In 1984, we found that if the soil was saturated during egg-hatch (between JD 155 and 160) and the condition persisted for the next 16 days, larval establishment was prevented. In the remaining 4 years of this study, we observed differences in survival rates to adulthood in the untreated plots, the highest survival rate occurring in the years receiving the least amount of rainfall (Elliott et al. in press).

Precipitation patterns and soil moisture seem to have a greater influence on corn rootworm survival to adulthood if soil insecticides have been applied (Figure 2). The lowest level of adult emergence from insecticide-treated plots occurred in 1980 and 1982, when 4 to 5 inches of rainfall occurred during late larval development (1980) or during the pupal stage (1982). In 1985, little rainfall occurred during the larval feeding period (June). During that year, more adults emerged from most of the insecticide-treated plots (Table 1 and Figure 1) than from the untreated plots. Table 2 shows the rates of beetle emergence over all infestation rates and for all years of the study for each insecticide treatment. Suppression of adult emergence by insecticide treatment seems to correlate with the water solubility of the insecticides. We believe that the more soluble compounds move more laterally and vertically into the soil profile surrounding the host plant root system; so the probability of the toxin contacting its target increases. Inherent toxicity of each compound does not seem to correlate with levels of adult suppression.

In another study, we used the controlled infestation technique to regulate WCR populations and we used irrigation to vary soil moisture in ridge-tilled plots. An equivalent plot was established without irrigation. That year, precipitation was adequate for corn production. However, on July 10, a single application of 2 to 4 inches of water was made to all of the irrigated plots. The WCR at that time were in the pupal stage. We observed nearly a 50-percent reduction in adult emergence rate in the irrigated plots (Table 3). During this same study, we evaluated the performance of Counter and Furadan in irrigated and dryland ridge-tilled plots infested with known densities of WCR eggs. We recorded a 71.6-percent reduction in beetle emergence rates in the Counter-treated plots and an increase of 21.4 percent in beetle emergence in Furadan-treated plots compared with beetle emergence rates in untreated plots.

These data support the early recommendations for corn rootworm management by Tate and Bare (1946). When their recommendations were made, our contemporary organophosphate and carbamate insecticides were not available for corn rootworm control. At that time, the cyclodiene insecticides were still being evaluated for soil insect control. Their extensive use in the 1950s quickly led to the development of resistant strains of both WCR and NCR. Reports in the early 1950s indicated that the highly persistent cyclodienes, which were also broadcast and incorporated in the topsoil, suppressed beetle populations by 98 to 99 percent. Soil moisture probably did not affect efficacy of the cyclodienes as much as it seems to affect the efficacy of carbamates and the organophosphate classes of insecticides. On the positive side, the lower level of control provided by contemporary organophosphate and carbamate insecticides, the diversity of compounds, and the dispersal and migratory habits of WCR populations have prevented the development of their resistance to insecticides. Our data also indicate that proper timing of irrigation, if available, could be an effective management tool for suppressing corn rootworm adult emergence.

The drought conditions that occurred across a major portion of the Corn Belt during the summer of 1988 created a favorable environment for corn rootworm larval survival and their ability to inflict stress on the host plant. The efficacy of planting time applications of soil insecticides in 1988 probably paralleled the results of our experiments in 1985. Based on weather and crop reports from around the Corn Belt, conditions may have been even worse than they were in 1985.

Table 1. Number of Beetles Emerging per Row Foot: Average for All Rates of Infestation

Treatment	Female	Male	Total
Mocap	2.2 a*	1.2 a*	3.4 a*
Untreated check**	2.6 a	4.8 c	7.4 bc
Furadan	3.4 ab	3.0 b	6.4 b
Counter	4.7 bc	4.3 bc	8.9 bcd
Amaze	5.0 c	3.9 bc	8.9 bcd
Lorsban	5.3 c	5.1 c	10.4 d
Thimet	5.6 c	4.2 bc	9.8 cd
Dyfonate**	7.5 d	2.9 b	10.4 d

*Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.01).
**Significant differences in sex ratio (p = 0.01).

Table 2. Effect of Insecticide Treatment on Rates of Adult Emergence

Treatment	Adult emergence (number per 0.3-m row)	Percent control*	LC_{50} (ppm) larvae	Water solubility (ppm)
Untreated	34.2 a**	...	...	...
Lorsban	27.4 a	19.9	0.26	2
Dyfonate	22.1 b	35.4	0.25	13
Thimet	22.0 b	35.7	0.08	50
Counter	18.3 c	46.5	0.04	45
Amaze	17.7 c	48.2	0.29	20
Furadan	16.0 c	53.2	0.56	700
Mocap	11.2 d	67.3	0.41	700

$*\frac{\text{Untreated - treated}}{\text{untreated}}$ = percent control.
**Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.01).

Table 3. Number of Western Corn Rootworm Beetles in Emergence Cages in Irrigated and Dryland Corn

No. beetles in irrigated corn	No. beetles in dryland corn	Degrees of freedom	X^2value	Prob. $>X^2$
2,078	3,875	1	482.48	.0001

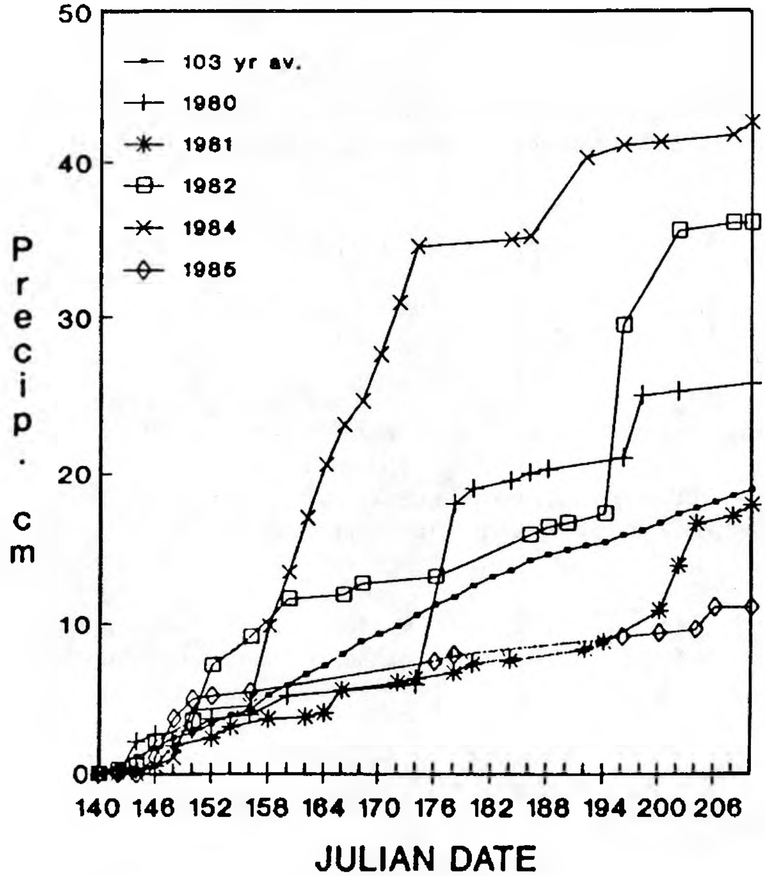

Figure 1. Accumulative precipitation in insecticide plots.

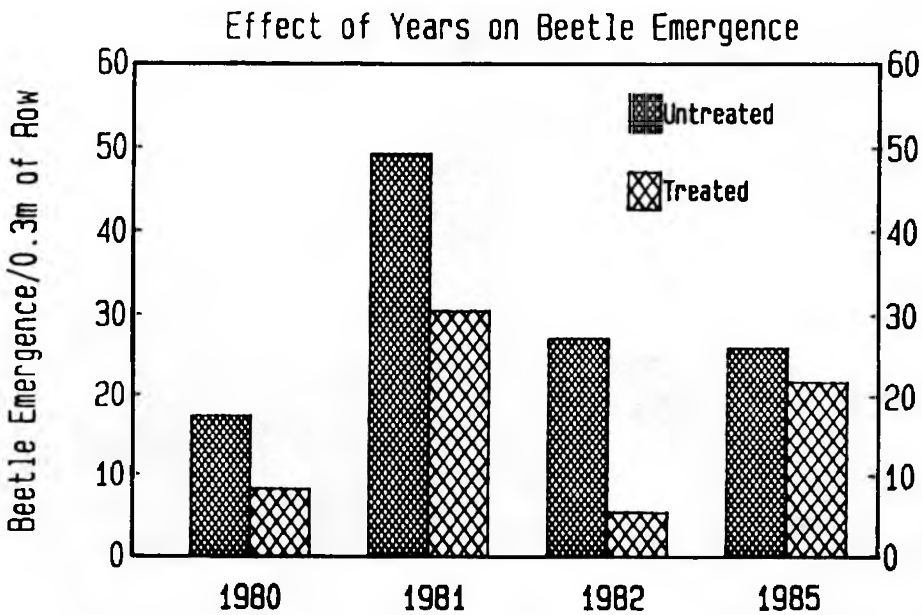

Figure 2. Effect of insecticide treatments over years on beetle emergence from 1980 to 1985.

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Insect Management: Making Decisions for Unique Circumstances

R. Weinzierl and K. Steffey

Most definitions of integrated pest management (IPM) stress well-planned utilization of cultural practices and applications of biological and chemical controls to adequately reduce pest-related losses in a manner that is environmentally acceptable and economically profitable. Some IPM practices can be regarded as general recommendations that can be applied with little modification in nearly all situations. Crop rotations, planting dates, and tillage practices, for instance, often can be expected to yield a similar pest management effect throughout a local area or even an entire geographic region. For example, a corn-soybean crop rotation is a cultural practice that prevents western corn rootworm damage in corn throughout the Corn Belt. Another broadly applicable IPM practice is the utilization of area-specific Hessian fly-free planting dates that guide the planting of winter wheat at times that avoid damage by this pest.

Other IPM practices require that decisions be made for specific fields. Field-specific decisions are especially important for the application of insecticides. In many instances, it is possible to monitor insect populations in individual fields and to apply effective controls as soon as populations reach a critical level. Such use of scouting results and established economic thresholds (critical population levels above which control is recommended) is a widely recognized component of IPM.

The use of scouting information and economic thresholds represents one aspect of decision making in unique circumstances. In any year, each field in an area presents a unique mixture of conditions, and the best pest management decisions for that field will result from knowledge provided by a thorough scouting program. Field-specific decisions allow control efforts to be directed where they are needed, and not elsewhere.

Field-specific decisions are, in most years, based on some well-established background information. Relationships between pest density and damage are known for several key pests, and the optimum timing for management efforts also has been established for many situations. Where potential losses caused by pests can be estimated in units of yield, crop prices often can be estimated accurately so that yield reductions can be expressed in dollar amounts. In many common situations, field-specific decisions, although unique, represent straightforward application of general rules. Unfortunately, such straightforward applications were not always possible in the Midwest during the summer of 1988.

The record drought conditions of 1988 altered pest population levels, distorted the usual synchronization of crop and pest development, reduced crop yields, and contributed to increased but highly variable crop prices. This paper examines a few examples of the insect pest management decision-making difficulties associated with the 1988 season. It reviews selected pest problems, describes how decision-making questions were answered, evaluates the results of these answers, and presents ideas about future approaches.

Bean Leaf Beetle, *Cerotoma trifurcata* (Coleoptera: Chrysomelidae)

The bean leaf beetle overwinters in Illinois as an adult. Adult population density gradually declines from early May through late June as these insects feed, deposit eggs, and die. The first summer generation of adult beetles peaks in late June or early July in most years, and peak numbers of second generation adults occur in mid-September. (See Kogan et al. 1988 and Kogan and Kuhlman 1982 for descriptions of the bean leaf beetle life cycle). As soybeans emerge and begin vegetative growth, feeding by overwintered bean leaf beetles can result in stand reductions, cotyledon damage, or varying degrees of defoliation. The first summer generation rarely causes damage to soybeans because plants are growing vigorously enough to tolerate moderate levels of defoliation. The second generation of adult bean leaf beetles often feeds on maturing pods, and along with associated fungal infections, can cause yield losses and reductions in seed quality.

Kogan (1976) and Kogan et al. (1980) proposed a static economic injury level and an economic threshold for early-season bean leaf beetle infestations, and Kuhlman and Steffey (1987) utilized this and similar information to suggest that early-season bean leaf beetle control should be initiated under the following circumstances: (1) before true leaves are expanded, if one cotyledon per foot of row is destroyed, and there are 5 or more beetles per foot of row; or (2) once the unifoliate and first trifoliate leaves have expanded, if defoliation reaches 30 percent and there are 5 or more beetles per foot of row. Although published papers contain differing assessments of spatial distribution and necessary sampling plans for bean leaf beetles (Boiteau 1978; Waldbauer and Kogan 1976), current sampling recommendations call for examination of 5 feet of row at each of 5 locations per field (Briggs et al. 1984). Using these criteria, early-season sampling is a quick and inexpensive process. Boiteau et al. (1979) reported that mid-day sampling (from 11:00 a.m. to 3:00 p.m.) might produce erratic results because bean leaf beetles are active fliers during this period; but scheduling sampling to avoid this time period presents only a minor inconvenience.

The recommended threshold for the period from bloom to pod fill is 20 percent defoliation and 16 or more beetles per foot of row; during the period of pod maturation, control is recommended when 5 to 10 percent of the pods are damaged and infestations reach or exceed 10 beetles per foot of row (Kuhlman and Steffey 1987). Recommendations for late-season sampling also call for examination of 5 feet of row at 5 sites per field; use of a ground cloth or beat sheet is advised when plants are large enough that visual examination becomes difficult (Briggs et al. 1984). Kogan et al. (1988) offered slightly different thresholds for late-season damage, but these authors also noted that poor correlations between beetle density and pod feeding estimates and poor correlations between pod feeding and yield and seed quality reductions prevent precise estimates of an economic injury level and an economic threshold.

Utilizing sampling procedures for bean leaf beetles was especially important in 1988 because, unlike most years in Illinois, this pest was present at economically damaging levels in many fields. The reasons for unusually high populations and increased damage remain unclear, but it is possible that dry conditions limited fungal diseases that may have otherwise killed a greater percentage of the bean leaf beetle population. Slow growth of seedling soybeans also favored increased damage because young plants did not "outgrow" insect defoliation as rapidly as usual.

Insecticides were applied to control overwintering bean leaf beetles in an estimated 100,000 acres of soybeans in Illinois in 1988. An estimated 200,000 acres of soybeans were treated to prevent late-season damage by second generation beetles. Based on widespread reports of field observations and spray decisions, it seems likely that only a small percentage (as low as 10 percent) of the early-season sprays were actually warranted. A much greater proportion of the late-season treatments seems to have been justified. It is important to note that the treated acreage represents only a small portion of the state's nine million acres of soybeans. The fact that some fields benefited from treatment while other fields did not require insecticide applications illustrates the value of scouting individual fields and saving the costs of unnecessary treatments.

But were the decisions concerning bean leaf beetle control really correct when drought-related yields and prices were considered? An ideal and dynamic threshold for the bean leaf beetle would incorporate estimates of probable yield, price, and treatment costs, as well as likely reductions in yield that would result from specific infestation densities. For early-season bean leaf beetle control, such a dynamic threshold is unlikely to be practical. At the time that control decisions must be made, plants are at the seedling stage, and yields and prices are extremely uncertain. Because of this uncertainty, an economic threshold established at the infestation level likely to cause a 5 to 8 percent loss in yield will remain appropriate and realistic.

Potential yield and price information can be estimated fairly accurately at the time when control efforts are considered for the prevention of pod damage caused by second generation beetles. Unfortunately, relationships between beetle density and yield or seed quality loss are poorly understood; consequently, it is not yet possible to recommend a precise and dynamic method for making decisions about control needs for this generation either. It is not possible to judge precisely whether or not the decision-making criteria for bean leaf beetle management gave absolutely correct results in 1988, but these criteria do appear to have been effective.

The preceding paragraphs illustrate that established guidelines for determining the need to control bean leaf beetles are not very precise, and that these guidelines are not readily modified to fit an unusual season. Because the bean leaf beetle is rarely economically damaging in Illinois soybeans, it is unlikely that great amounts of funding will be devoted to improving our decision-making methodology for this pest. Our message is that, in some instances, general background information may not enable us to modify our decision-making methods to fit truly unique circumstances. For minor pests, it is unlikely that we will improve these methods in the near future. Still, thresholds currently in use provide fairly effective guidance.

Corn Rootworms, *Diabrotica* spp. (Coleoptera: Chrysomelidae)

Unlike the bean leaf beetle, corn rootworms frequently are economically important pests. It's interesting to examine whether or not the greater importance of corn rootworms has resulted in the development of more precise thresholds or the generation of more information that would enable pest managers to modify decision-making practices during drought or other unusual circumstances. This paper will not address the efficacy of soil insecticides or the value of root ratings, larval counts, or other measures of larval density or damage. Instead, it will focus on monitoring and managing adult beetles.

Adult corn rootworm beetles can reduce yields in field corn and sweet corn by feeding on silks and preventing pollination (Martin et al. 1967; Kuhlman and Moore 1968). Current recommendations advise producers to control corn rootworm adults to prevent reductions in pollination if beetle densities reach or exceed 5 per plant when 25 to 50 percent of the plants have silked (Kuhlman and Steffey 1987). No guidelines have been proposed to adjust this threshold according to expected yields. For insecticide applications to prevent losses, treatments must be applied when silks are fresh before they turn brown.

Monitoring or controlling adult beetles also is important in relation to the next season's damage potential and control needs if corn is to be grown in the same field again the next year. Tollefson (1975) found a significant correlation between corn rootworm beetle numbers in corn and larval damage in the next year's corn crop. Studies conducted by Foster et al. (1982) and Steffey et al. (1982) have contributed to the development of sampling plans designed to determine control needs based on adult populations. Current recommendations call for corn rootworm control to prevent larval damage if the previous season's beetle infestations exceed 0.5 to 0.75 beetle per plant (Kuhlman and Steffey 1987). The value of adult corn rootworm population estimates for predicting the next year's root damage has been questioned (Foster et al. 1986), and some pest managers recommend application of soil insecticides in all instances where corn is grown in the same field in consecutive seasons. Where adult control programs are utilized to prevent egg-laying (and thereby prevent damage the next season), beetle counts must be maintained below 0.5 to 0.75 beetle per plant throughout the egg-laying period in July and August.

Sampling and decision making based on corn rootworm adult counts were, like many other decisions, complicated by drought conditions in 1988. Because dry soils contributed to erratic germination and plant growth, individual fields exhibited great variation in the stage of corn plant growth when beetles emerged and began feeding in July. Beetle populations that usually would have been distributed throughout a field were concentrated in portions where plants were more mature and silking. Although average densities throughout a field may have been subeconomic, certain areas faced excessive damage. In addition, pollination and yield were threatened directly by drought; the combined effects of beetle damage and drought stress were (and still are) poorly understood. In some instances, anticipated yields were so low that no additional expenditures, including insect control costs, seemed appropriate. The result was that producers were advised to estimate the fraction of the field infested and to determine whether or not that fraction was likely to produce a significant portion of the field's total yield. Where the infested, silking plants appeared to represent an investment worth saving, control was recommended if infestations exceeded 5 beetles per plant. In other instances, producers were advised not to treat to protect early-silking plants, but to wait to determine control needs until the majority of the plants had begun to silk. This rather vague and general response may seem inadequate, but a more precise response is not possible without a more thorough understanding of the relationship between pest density and yield loss under a range of conditions. Field-specific decisions were possible in 1988 and will be possible in the future, but some intuition and broad judgment remain necessary as substitutes for detailed supporting data.

What about basing soil insecticide plans in 1989 on beetle counts in 1988? The drought's effects on the beetle's reproductive potential and the survivorship of eggs remain somewhat unclear. Although 1988 beetle populations may not produce as many larvae as are normally expected, it is probably an unwise risk to adjust thresholds upward to reflect this possibility. Where beetle counts are utilized to determine soil insecticide needs, control is still recommended where counts exceed 0.5 beetle per plant in first-year corn or 0.75 beetle per plant in second-year (or more continuous) corn.

European Corn Borer, *Ostrinia nubilalis* (Lepidoptera: Pyralidae)

The European corn borer is a major pest throughout the Corn Belt. In most of Illinois, two generations develop each year. Overwintering larvae pupate in late spring, and first-generation moth flight occurs in June and July. Female moths prefer to deposit their eggs on the leaves of mid- to late-whorl stage corn. Larvae feed on leaves and subsequently move down the whorl and into stalks. Second-generation moth flight occurs from late July through early September. These moths prefer to deposit their eggs on later planted, less mature corn. Second-generation larvae enter stalks, feed, and commonly enter diapause and overwinter within the stalk; in some seasons, a portion of these larvae continue development, emerge as adults, and produce a third generation. Showers et al. (1983) and Kuhlman and Steffey (1987) have summarized European corn borer biology and the sampling methods and decision-making criteria utilized in determining control needs.

The dry conditions that limited corn growth and yields in 1988 also seem to have limited first-generation corn borer problems in many areas. Although infestations were not widespread, sampling and decision making were still necessary. The difficulties associated with first-generation corn borer control decisions in 1988 can be summarized by using the worksheet illustrated in Figure 1. This worksheet can be used to incorporate yield estimates, crop price estimates, and treatment costs in determinations of the net gain or loss provided by an insecticide application.

The use of first-generation decision-making computations is depicted in Table 1. For each of three infestation levels, a range of potential yields and commodity prices is used in the calculations outlined in Figure 1. All calculations assume that a granular insecticide will be used and that it will result in an 80-percent reduction in yield loss. Treatment cost is estimated to be $14.00 per acre. The results provided by these computations (see Table 1) indicate the great variation in economic outcomes that might have been expected at the time control decisions were made in July. Given the range of anticipated yields used in these examples (40 to 120 bushels per acre), even a high market price for corn ($3.00 per bushel) would not justify controlling an infestation of 0.5 borer per plant. As infestation estimates are increased, control costs are balanced by yield savings, so that if borer populations were great enough (unlikely in the conditions experienced in 1988), treatment might even be justified where anticipated yields were as low as 40 bushels per acre (if infestation = 4 borers per plant and corn price = $3.00 per bushel). Although the parameters presented in Table 1 may seem to include some extreme values, it is important to note the actual range in yields and prices experienced in 1988. It is also important to remember that yield and price estimates were very uncertain at the time first-generation control decisions were made in July.

A similar decision-making worksheet can be utilized for calculating the economic gain or loss resulting from second-generation European corn borer control (Figure 2). The use of this worksheet is illustrated in Table 2. Combining different infestation levels, potential yields, and commodity prices produces a wide range of economic outcomes. In all instances presented in Table 2, insecticide application is presumed to cost $14.00 per acre and to reduce yield losses by 75 percent. As for first-generation control decisions, lower infestations (in this example, 1 egg mass per plant) warrant control only if yield and price estimates are fairly high. Where infestations are greater (2 egg masses per plant), treatment might be justified even where expected yield is not so great.

These examples of the decision-making process for European corn borer control do not specifically address drought-induced reductions in crop performance. It is unclear whether or not the estimates of "loss per borer" or corn borer survivorship utilized in the worksheets are accurate for drought-stressed plants. In addition, the accuracy of estimates of potential yield and crop price also can be questioned, especially when such estimates must be made rather early in the summer when first-generation controls must be applied. Nonetheless, these examples do illustrate that decisions can be customized to address truly unique conditions that differ among individual fields. The most important information that allows such modification is a practical estimation of the mathematical relationship between pest density and yield loss.

CONCLUSIONS

Our abilities to make field-specific pest management decisions are greatest during "normal" years in which pest impacts, weather effects, potential yields, and probable prices are readily estimated. In truly unique circumstances, such as those encountered during 1988, established thresholds may be hard to apply to unusual situations. These estimates still offer useful guidance, however, as was the case for bean leaf beetle and corn rootworm adult thresholds. Adjustable, dynamic thresholds provide a more thorough computation of the costs and benefits of pest management actions, but the determination of such thresholds requires a greater understanding of the relationship between pest density and yield loss. Only in rare instances does our understanding of pest density and yield relationships include knowledge of what to expect in unusual circumstances such as extreme drought. Nonetheless, general guidelines that are available provide extremely useful information that is far superior to attractive advertising, spray calendars, or neighbors' encouragement as aids in making management decisions.

Table 1. Results of Decision-Making Computations to Determine the Value of Control Actions Against First-Generation European Corn Borer. Based on Figure 1 and Assumptions that a Granular Insecticide Provides 80-Percent Reduction in Yield Loss and that Treatment Cost is $14.00 per Acre

Borers/ plant	Estimated yield (bu/A)	Bu loss/A	$/bu	$ loss/A	Preventable $ loss/A	$ net gain or loss/A
0.5	40	1	$1.80	$ 1.80	$ 1.44	-$12.56
0.5	40	1	2.50	2.50	2.00	- 12.00
0.5	40	1	3.00	3.00	2.40	- 11.60
0.5	80	2	1.80	3.60	2.88	- 11.12
0.5	80	2	2.50	5.00	4.00	- 10.00
0.5	80	2	3.00	6.00	4.80	- 9.20
0.5	120	3	1.80	5.40	4.32	- 9.68
0.5	120	3	2.50	7.50	6.00	- 8.00
0.5	120	3	3.00	9.00	7.20	- 6.80
2	40	4	1.80	7.20	5.76	- 8.24
2	40	4	2.50	10.00	8.00	- 6.00
2	40	4	3.00	12.00	9.60	- 4.40
2	80	8	1.80	14.40	11.52	- 2.48
2	80	8	2.50	20.00	16.00	+ 2.00
2	80	8	3.00	24.00	19.20	+ 5.20
2	120	12	1.80	21.60	17.28	+ 3.28
2	120	12	2.50	30.00	24.00	+ 10.00
2	120	12	3.00	36.00	28.80	+ 14.80
4	40	8	1.80	14.40	11.52	- 2.48
4	40	8	2.50	20.00	16.00	+ 2.00
4	40	8	3.00	24.00	19.20	+ 5.20
4	80	16	1.80	28.80	23.04	+ 9.04
4	80	16	2.50	40.00	32.00	+ 18.00
4	80	16	3.00	48.00	38.40	+ 24.40
4	120	24	1.80	43.20	34.56	+ 20.56
4	120	24	2.50	60.00	48.00	+ 34.00
4	120	24	3.00	72.00	57.60	+ 43.60

Table 2. Results of Decision-Making Computations to Determine the Value of Control Actions Against Second Generation European Corn Borer. Based on Figure 2 and Assumptions that Two Larvae from Each Egg Mass Survive to Enter stalks, Insecticide Application Reduces Yield Losses by 75 Percent, and Treatment Cost is $14.00 per Acre

Egg masses/ plant	Estimated yield (bu/A)	Bu loss/A	$/bu	$ loss/A	Preventable $ loss/A	$ net gain or loss
1	40	3.2	$1.80	$ 5.76	$ 4.32	-$ 9.68
1	40	3.2	2.50	8.00	6.00	- 8.00
1	40	3.2	3.00	9.60	7.20	- 6.80
1	80	6.4	1.80	11.52	8.64	- 5.36
1	80	6.4	2.50	16.00	12.00	- 2.00
1	80	6.4	3.00	19.20	14.40	+ 0.40
1	120	9.6	1.80	17.28	12.96	- 1.04
1	120	9.6	2.50	24.00	18.00	+ 4.00
1	120	9.6	3.00	28.80	21.60	+ 7.60
2	40	6.4	1.80	11.52	8.64	- 5.36
2	40	6.4	2.50	16.00	12.00	- 2.00
2	40	6.4	3.00	19.20	14.40	+ 0.40
2	80	12.8	1.80	23.04	17.28	+ 3.28
2	80	12.8	2.50	32.00	24.00	+ 10.00
2	80	12.8	3.00	38.40	28.80	+ 14.80
2	120	19.2	1.80	34.56	25.92	+ 11.92
2	120	19.2	2.50	48.00	36.00	+ 22.00
2	120	19.2	3.00	57.60	43.20	+ 29.20

Management Worksheet
for First-Generation
Corn Borer

_______ % of 100 Plants Infested × _______ Average No. Borers/Infested Plant = _______ Borers/Plant
(determined by checking whorls from 10 plants)

_______ Borers/Plant × 5% Yield Loss/Borer = _______ % Yield Loss

_______ % Yield Loss × _______ Expected Yield (Bu/A) = _______ Bu/A Loss

_______ Bu/A Loss × $___________ Price/Bu = $___________ Loss/A

$___________ Loss/A × _______ % Control = $___________ Preventable Loss/A
(80% for granules)
(50% for sprays)

$___________ Preventable Loss/A − $___________ Cost of Control/A =
$___________ Gain (+) or Loss (−) per acre if treatment is applied

Figure 1. Management worksheet for first-generation European corn borer.

Management Worksheet
for Second-Generation
Corn Borer

_______ Number of Egg Masses/Plant × 2 Borers/Egg Mass* = _______ Borers/Plant
(cumulative counts, taken 7 days apart)

_______ Borers/Plant × ___4___ % Loss/Borer** = _______ % Yield Loss

_______ % Yield Loss × _______ Expected Yield = _______ Bu/A Loss

_______ Bu/A Loss × $___________ Price/Bu = $___________ Loss/A

$___________ Loss/Acre × ___75___ % Control = $___________ Preventable Loss/A

$___________ Preventable Loss/A − $___________ Cost of Control/A =
$___________ Gain (+) or Loss (−) per acre if treatment is applied

* Assumes survival rate of 2 borers/egg mass.
** Use 3% per borer per plant if infestation occurs after silks are brown. The potential economic benefits of treatment decline rapidly if infestations occur after corn reaches the blister stage.

Figure 2. Management worksheet for second-generation European corn borer.

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Effects of the 1988 Drought on Plant Diseases for 1989

M. Shurtleff and W. Kirby

The 1988 record summer heat and drought should have little effect on the number and severity of diseases of corn, soybeans, small grains, and alfalfa that we will see in Illinois in 1989. Why? The pathogens causing the diseases of these crops overseason in the soil or in plant debris either above or below the soil surface. Even though foliar diseases were kept in check by last summer's heat and drought, these organisms are still in Illinois's fields lying dormant and waiting for the right environmental conditions to once again become active.

Root-rotting pathogens and the majority of crown, stem, and stalk-rotting organisms overwinter in the soil or in crop debris in the soil and are considered to be soil inhabitants, that is, part of the natural soil microflora, rather than soil invaders. These latter pathogens, primarily those that attack the foliage and reproductive organs, generally remain viable in plant debris until that debris is thoroughly decayed, a process that may take from 1 to 3 years or more. If the plant refuse is on or above the soil surface, the pathogens generally remain viable for an extra year or two longer than in debris buried in the soil.

Some pathogens, such as the rust fungi and some leaf-spotting or leaf-blighting organisms, blow into Illinois on southerly winds each spring and summer from their overwintering "homes" in the southern states. This is also true of certain virus diseases, such as barley yellow dwarf of small grains, which is transmitted by aphids that are wind-carried from the south. A wet spring and early summer, however, will result in a heavy aphid kill from fungal diseases. The same is true of other viruses that are vectored by insects. The hot, dry summer of 1988 allowed high populations of virus-carrying insects, especially of aphids and leafhoppers, to build up. We will have more perennial weeds that are virus-infected in and around our fields in 1989. It might be wise for farmers who suffered losses from virus diseases to treat their field borders before planting with a broadleaf-killing herbicide.

Another control suggestion for 1989: Charcoal rot was the most serious disease of soybeans this past year (read the presentation by D.M. Eastburn). Some farmers may wish to lower the number of overwintering microsclerotia, the mechanism by which the charcoal rot fungus survives from season to season. Because this fungus has a wide host range and no resistance is available in soybeans, corn, sorghum, or other crops, a clean and deep plowdown may be advisable to bury the microsclerotia to plow-sole depth where, hopefully, they will decay before crop plants can become infected this coming summer and early fall.

The crop diseases we can expect in 1989 will depend largely on the weather conditions, especially the amount and distribution of rainfall during this coming spring and summer. Table 1 lists the potential damage from some common plant diseases we can expect in 1989, depending on the rainfall.

In summary, the diseases we can expect in corn, soybeans, small grains, and alfalfa in 1989 will depend much more on whether we have a wet, normal, or dry spring and summer than on last summer's drought.

Table 1. Potential Damage from Some Common Plant Diseases in Illinois, Depending on the Rainfall During the Spring and Summer

Crop	Disease	Wet spring and/or summer	Normal spring and/or summer	Dry spring and/or summer
All plants	Crown and root rots, leaf spots and blights, seed rot, damping-off	Heavy	Light to moderate	Doubtful
Small grains	Foliage diseases, rusts, scab, glume blotch	Heavy	Light to heavy	Doubtful
Small grains	Yellow dwarf (virus)	Doubtful to light	Light to heavy	Light to heavy
Corn	Leaf blights, stalk rots, ear rots	Moderate	Light	Doubtful to light
	Common smut	Doubtful to light	Doubtful to light	Moderate
Soybeans	Foliage diseases, Phytophthora root and stem rot, pod and stem blight, stem canker, anthracnose	Heavy	Light	Doubtful
Alfalfa	Foliar diseases, Phytophthora root rot	Moderate to heavy	Moderate	Light

Effects of the 1988 Drought on Insects for 1989

D. Kuhlman

One of the questions posed to entomologists in recent months has been, "How will the drought of 1988 affect the potential for insect problems in 1989?" Although we almost always have solutions for controlling insect pests, our ability to forecast outbreaks, based on previous weather conditions, is somewhat limited. That's because the interaction of agronomic practices, climate, and size and survival of overwintering beneficial and pest populations makes it difficult to forecast how the hot, dry weather of 1988 will affect the potential for insect problems in 1989. Like the growers, we'll have to wait and see.

Everyone knows that the drought and high temperatures influenced populations of certain insects in 1988 and, most notably, the tremendous outbreak of twospotted spider mites in soybeans. The remainder of this paper will be devoted to reviewing some of the drought-aggravated insect pest problems that occurred in 1988 and making some predictions about insect problems in 1989. Much of what we say regarding the effects of drought conditions in 1988 on insect populations in 1989 will be speculation. However, we can make some educated guesses about insect populations in 1989 based on the biology of the insect pests and our own past experience.

TWOSPOTTED SPIDER MITES

Are they going to be a serious problem in 1989? Will the high populations of mites in 1988 successfully overwinter in numbers significant enough to cause problems in 1989? We know that mites usually spend the winter as female adults in sheltered areas. And even if a larger than normal population of spider mites successfully overwinters in protected areas, climatic conditions will have to be favorable in 1989 to sustain high populations. Favorable conditions for mites, of course, would be extended periods of hot and dry weather, such as occurred in 1983 and 1988.

A review of past records indicates that twospotted spider mites were a big problem in 1983, a dry season, when about 2.9 million acres of soybeans were treated in Illinois. In the past 10 years, excluding the drought years of 1983 and 1988, Illinois farmers have annually treated between 52,000 and 234,000 acres of soybeans to control spider mites. This represents about 0.5 to 2.5 percent of the Illinois soybean acreage. We don't know how many acres of soybeans were treated for spider mites in 1988, but some authorities have estimated that about 4 million acres, or 45 percent of all Illinois soybeans, were treated with an insecticide at least one time from June through August.

What lessons did we learn from the spider mite outbreak in 1988? Many will agree that the main lesson learned was to treat soybeans promptly at the first symptoms of mite injury. Secondly, and perhaps just as important, sprays applied to field perimeters did not adequately control mites in many situations. Some farmers who spot-treated were unaware that mites were already present in the interior of the field because symptoms of damage had not yet appeared. As a result, a second application had to be made to the field a week or 10 days after the perimeter treatment had been applied.

BEAN LEAF BEETLE

A large population of bean leaf beetles was present in the fall of 1987 and survived the mild winter of 1987-1988 in large numbers. The large adult population and high survival, coupled with early planting of soybeans in 1988, resulted in many fields of newly emerging soybeans being damaged, particularly in the area between Interstates 70 and 80. However, feeding damage and yield losses caused by this overwintering population of bean leaf beetles were negligible, even in fields that were not sprayed.

The hot, dry summer of 1988 apparently did not reduce the survival of first- or second-generation bean leaf beetle populations. The second generation was unusually large, and many growers in central Illinois had to spray soybean fields in late August and early September to prevent pod feeding by the adults.

Will bean leaf beetles be a problem in 1989? If there is a mild winter and soybeans are planted early in 1989, it is likely that the bean leaf beetle will garner the "insect-of-the-week" award in mid-May, just as it did in 1988.

GRAPE COLASPIS

This insect pest is seldom a problem in Illinois. When this tiny grub has caused damage in the past, it has usually occurred in corn following clover. Imagine our surprise when reports and questions about grape colaspis damage to newly emerging soybeans began to materialize in late May and early June of 1988. It's no exaggeration to say that Extension entomologists received reports of hundreds of soybean fields being damaged by tiny grape colaspis larvae feeding on the roots of seedling soybean plants. Their feeding, coupled with a lack of soil moisture, reduced some soybean stands by 95 percent in some extreme situations. We know of some farmers who had to replant soybeans twice due to grape colaspis damage.

Why was this insect such a problem on soybeans in 1988? A combination of several factors probably contributed to an increase in grape colaspis populations. It's likely that fields in the PIK program in 1983 and set-aside acres seeded to legumes in subsequent years have provided a reservoir for a buildup of grape colaspis populations. Furthermore, some relatively mild winters have probably favored the survival of the overwintering grub stage.

Will the grape colaspis cause problems in soybeans and corn in 1989? The answer is "probably," but it's difficult to predict which fields will be infested and the extent of the damage in any given field. In 1988, most reports of grape colaspis damage were in fields of soybeans that followed soybeans or set-aside acres seeded to a legume. We received only a few reports of grape colaspis damage to soybeans following corn--and, surprisingly, there weren't many reports of damage to corn following soybeans.

In 1989, if at all possible, we would encourage farmers to avoid planting soybeans after soybeans or after legume set-aside acres. If a farmer experienced grape colaspis damage to soybeans in 1988, should he or she apply a soil insecticide on soybeans in 1989? The answer is an emphatic "no." First of all, there aren't any soil insecticides labeled to control grape colaspis larvae in soybeans *or* corn. Although Furadan 15G, Lorsban 15G, Mocap 15G, and Thimet 20G are labeled for soybeans, we advise against their use on soybeans to control grape colaspis larvae.

Finally, let's consider the seasonal life history of the grape colaspis. It overwinters as a tiny grub in the soil. In the spring as the temperature rises, the grubs move upward to feed on small roots of corn and the hypocotyl or roots of soybeans. Upon completion of their feeding in mid-June, the larvae pupate and emerge as adults in late June and July. The adults feed on soybean foliage, pigweed, corn silks, lambsquarters, alfalfa, and clover to meet their nutritional needs. Egg-laying occurs from June through August, and egg-hatch occurs in late fall. There is usually only one generation per year.

EUROPEAN CORN BORER

It may seem like grasping for a straw in a tornado, but there was one entomological benefit from the drought in 1988. The hot, dry summer drastically reduced the survival and populations of both the first- and second-generation European corn borer (ECB). As a result, yield losses from the ECB were virtually nonexistent, and few, if any, fields needed treatment in Illinois.

Corn borer survival is very dependent on weather conditions that prevail during adult mating, egg-laying, and larval development immediately after egg-hatch. High temperatures and low humidity in 1988 caused an increase in egg desiccation and mortality of newly hatched larvae. Many people will recall that there were few summer nights when dew formed on vegetation during corn borer moth flight in May (spring brood) and late July (summer brood). Moisture in the form of dew droplets or rain is important to the successful mating of ECB male and female moths. After drinking rain or dew droplets, the female ECB moth begins to emit a sex attractant (pheromone) to attract the male for mating. Our hot, dry summer in Illinois had at least one advantage, albeit small, of impeding the mating of ECB male and female moths and reducing the potential for economic damage to virtually zero.

What's the potential for ECB in 1989? You can give a big assist to the drought of 1988 for reducing overwintering ECB larval populations to the lowest level since 1983 (Table 1). As a result, the potential for economic infestations of first-generation corn borers should be quite low in 1989. However, the single most important factor determining the extent of first-generation ECB infestations in 1989 will be the environmental conditions that the female moths encounter during their egg-laying activities. Experience and research have shown us that low overwintering ECB populations can result in economic infestations the following summer if:

1. A cool, dry spring enables farmers to plant early. The ECB moths emerge later, and the corn is sufficiently mature to attract egg-laying moths and ensure high larval survival.

2. Nights are warm and weather is calm during egg-laying and larval development in June.

3. The incidence of disease and parasitism is low.

4. Drought conditions do not prevail during egg-laying. Dry, hot, windy weather impedes the mating of ECB male and female moths and increases egg desiccation and larval mortality.

FALSE CHINCH BUG

A notable consequence of the 1988 drought was the appearance of several insect pests that are uncommon to Illinois agriculture. One of several "new" problems never before experienced by Illinois Extension entomologists was the false chinch bug, *Nysius ericae*, that appeared in tremendous numbers throughout the state during June and July.

Little is known about the extent of injury caused by the false chinch bug in field crops, nor do we know about the potential for damage by this pest in 1989. The false chinch bug has been recognized as a serious pest in the semi-arid regions of the United States. A 1918 paper by F.B. Milliken in the *Journal of Agricultural Research* stated, ". . . it causes great damage to sugar beets and cruciferous garden crops, settling upon them suddenly in enormous numbers and sucking so much sap from them that the plants wilt beyond recovery in one or two days."

In 1988, the false chinch bug was most frequently reported in no-till fields of corn or soybeans, or moving from set-aside acres and roadsides into field crops. They also appeared in huge numbers around farmsteads and residences, creating a nuisance to homeowners. In retrospect, the false chinch bug was not so much a pest of field crops as a nuisance and a curiosity in 1988.

Will the false chinch bug reappear in enormous numbers in 1989? If so, what should be done to control them? Our crystal ball doesn't reveal very much about the potential for this pest in 1989. The only recommendation we can offer is to watch fields carefully in 1989, particularly row crops adjacent to set-aside fields or planted into set-aside crops under no-till conditions. Although there are no insecticides labeled for false chinch bugs, those registered for chinch bugs (Asana, Lorsban, Pydrin, Sevin on corn) should give some control.

What does the false chinch bug look like? The adult is about 1/8 inch long and 1/16 inch wide, with clear wings and a dull gray body color with dark or black spots (Figure 1). The young nymphs are wingless, oval or pear-shaped, about 1/16 inch long, and have pinkish white or red markings. Under magnification, the nymphs have irregular brown and white stripes or mottling on the head and thorax, a broken white line down the center of the head that continues onto the thorax, and reddish mottling on the abdomen (Figure 2).

Based on the research he conducted in Kansas, Milliken reported that the false chinch bug overwinters as a nymph or an egg and completes its development very early the next spring. There may be as many as five generations per season, depending on climatic conditions. In Milliken's studies, it took about 28 days at temperatures of $80^{o}F$ to complete one full generation from egg to adult.

False chinch bugs have piercing-sucking mouth parts and feed during their nymphal and adult stages on plants such as creeping spurge, peppergrass, shepherd's purse, Russian thistle, rape, mustard, and other weeds. They also feed on corn and soybeans under extremely dry conditions, resulting in wilting of seedlings and browning of the leaf edges. Heavy infestations have been observed to kill significant portions of corn and soybean fields.

ALFALFA WEEVIL

The drought of 1988 was a key factor in causing an "explosion" of alfalfa weevil populations throughout Illinois. Damaging infestations were observed in early April in southern Illinois counties, and economic populations continued to be observed through late June in northern counties.

The spring of 1988 was mild enough for an extended egg-laying period. As a consequence, alfalfa fields were subjected to many stages of weevils ranging from early larval instars to adults. And, due to a dry spring, a beneficial fungus disease, *Erynia radicans*, had little impact in reducing weevil populations. Moisture and high humidity are necessary for this beneficial pathogen to become epidemic and keep weevils in check.

Alfalfa wasn't the only crop damaged by alfalfa weevils in 1988. A most unusual phenomenon that occurred was the migration of newly emerging alfalfa weevil adults from alfalfa into adjacent soybean fields where they fed on and destroyed soybean seedlings. In another situation, no-till soybeans planted into alfalfa were devastated by alfalfa weevil adults chewing on the hypocotyls and stems of newly emerging soybeans. These atypical situations are the consequence of extremely large alfalfa weevil populations running out of a food supply (alfalfa) and seeking an alternative host plant (soybeans) to satisfy their appetites.

Will the drought of 1988 increase the potential for alfalfa weevil problems in 1989? The answer, in all probability, is yes. According to Steve Roberts, alfalfa insect researcher with the Illinois Natural History Survey, alfalfa weevil adult populations started migrating back into alfalfa fields in early October 1988 to lay eggs. Their migration from summer hibernation sites (woods, fence rows, etc.) into alfalfa was about three weeks earlier than normal. In addition, the adult weevil populations were much larger than normal. If warm temperatures (base 50°F) persist into late fall in 1988, allowing extended egg-laying, the potential for severe alfalfa weevil damage in 1989 is high.

CLOVER CUTWORM

Whenever a new crop is introduced into an area, some unexpected insect problems invariably occur. About 20,000 acres of canola were planted in the fall of 1988 in Illinois, according to some estimates. We have no information about the potential for insect problems on this new crop in Illinois. However, Rob Koethe, area adviser in pest management in Springfield, observed damaging infestations of the clover cutworm, *Dicestra trifolii* (Hufnagel), in several fields of canola in Macoupin County during mid-October of 1988. Populations of the clover cutworm ranged from 3 to 10 per square foot in these fields. This insect was also found damaging fall seedings of alfalfa in Coles, Champaign, and Bureau counties in 1988.

According to George Godfrey, research entomologist with the Faunistics Section of the Illinois Natural History Survey, the clover cutworm had not been detected in Illinois prior to 1988. Perhaps the hot, dry summer of 1988 contributed to the establishment of the clover cutworm, but this is only speculation.

The clover cutworm probably has several generations a year in Illinois. The larva, or damaging stage, is about 1 1/4 inches long when fully grown and has a green head. Its body color ranges from pale to dark green. Some specimens are almost black. A broad yellow-white or pinkish stripe extends from the head to the rear on each side. Pale green specimens have a pair of prominent dark dashes (like parenthetical marks) on the dorsum of each body segment. The adult stage, a moth, is about the same size as the true armyworm. This insect probably overwinters in Illinois as a pupa. In addition to feeding on canola, the clover cutworm also feeds on celery, lettuce, cabbage, asparagus, spinach, parsley, clover, sow thistle, pigweed, Russian thistle, radish, onion, lambsquarters, clover, and alfalfa. We can only encourage farmers who are growing canola for the first time to monitor the crop very closely in 1989. In the event that insect problems are encountered, farmers should contact their local county Extension advisers.

MIGRATORY INSECTS

Many insects migrate into Illinois each year from southern states, including important pests such as black cutworms, armyworms, and potato leafhoppers. The drought of 1988 will likely have little impact on their migration into Illinois or their potential for causing damage in 1989.

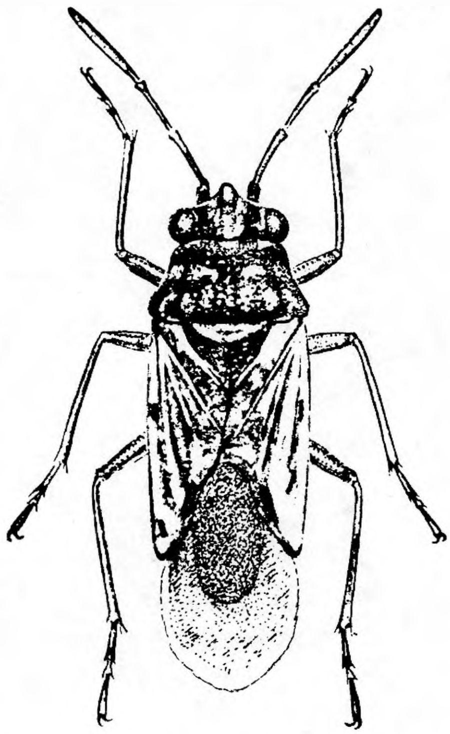

Figure 1. False chinch bug adult.

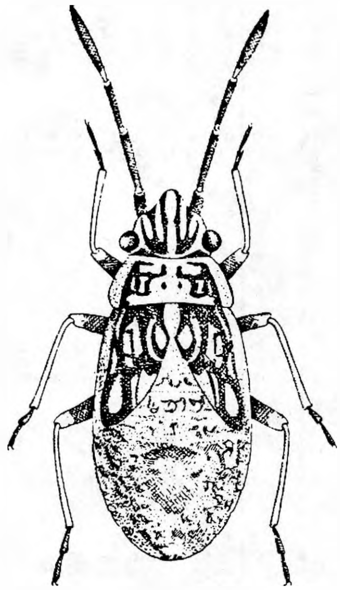

Figure 2. False chinch bug nymph.

Table 1. Second-Generation European Corn Borer Populations in Illinois, 1974-1988

	Average number of corn borer larvae per 100 plants														
Region	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Northwest	17	184	67	183	251	175	105	127	23	111	197	50	229	231	94
Northeast	12	73	11	36	223	152	130	105	0	21	33	37	120	225	53
West	28	64	67	247	412	72	134	69	17	92	202	145	144	177	149
Central	25	26	11	44	371	186	148	103	37	55	15	60	259	128	30
East	21	21	12	31	175	110	94	45	29	41	39	70	283	129	11
West-southwest	75	78	23	125	455	43	136	120	39	31	92	119	114	127	31
East-southeast	28	36	32	204	214	83	100	128	49	74	11	142	136	101	34
Southwest	30	45	36	288	239	38	206	121	24	6	14	122	400	144	48
Southeast	--	--	42	187	203	42	314	90	4	2	6	189	233	134	6
Average per region	30	66	34	150	283	101	152	101	25	49	68	104	214	156	51

NOTE: The 1988 European corn borer survey was conducted by area advisers in pest management Ann Carrick, Dixon; Rob Koethe, Springfield; and Noel Troxclair, Benton.

Wild Garlic Control

G. Kapusta

Wild garlic has been a serious weed problem in Illinois for many years. It was reported in 1944 that this weed was causing at least a half-million dollar loss annually in wheat. It is likely that losses have remained at least as high annually until 1987. Wild garlic rarely reduces wheat yield because it is not a very competitive species. Losses occur from the undesirable odor that aerial bulblets impart to wheat products during the milling process. Consequently, grain buyers discount the price of wheat that is contaminated with more than two garlic bulblets per 1,000 grams of wheat. The discount ranges from several cents to more than a dollar per bushel and usually is related to the market price of wheat. It is anticipated that a large wheat acreage will be planted in Illinois in the fall of 1988; thus, wild garlic could cause several million dollars worth of loss unless it is controlled.

Cultural and chemical control measures have been utilized for many years with only marginal success. The herbicides 2,4-D and Banvel have not provided consistent control because (1) the rates that wheat will tolerate usually are too low for effective control of wild garlic, and (2) temperatures often are too low for optimum herbicide efficacy in approximately early April, the only time during which wheat would tolerate these herbicides. One of the most effective methods of decreasing potential contamination of wheat with wild garlic bulblets is the establishment of a dense, vigorous stand of wheat. Because wild garlic is not a competitive species, the wheat often can reduce the height of the garlic so that aerial bulblets are not harvested with the wheat and frequently can decrease the wild garlic population. Wild garlic problems are most serious if the wheat stand is thinned or stunted due to frost, disease, or excessively wet fields. Under these conditions, enough light can penetrate the wheat canopy to allow the wild garlic to grow as tall as the wheat. Consequently, there is no way to avoid harvesting the bulblets during harvest of the wheat.

Because wild garlic is a perennial that reproduces in several ways, tillage is only partly effective in controlling this weed. Nonetheless, repeated tillage properly timed can help reduce the problem. Tillage in July, August, and September has little effect because the plants are dormant. Fall and early winter tillage is of marginal value because the disturbed plants may become reestablished. In addition, fall tillage exposes the soil to an extended period of erosion. Early spring tillage has been the most effective, according to experienced growers. It exposes the plant to freezing and drying at a time when most of the root reserves have been exhausted. The tillage also would prevent new underground bulbs from being formed. This is a major goal because they are the primary source for future infestation as hardshell bulbs can retain their viability in the soil for 6 years or more. Rotation to row crops is helpful only if the garlic is controlled between cropping seasons. This has been a major source of infestation because the garlic emerges shortly after corn and soybean harvest and may produce new bulbs if tillage is delayed the following spring due to wet fields. Another major source of infestation in recent years has been "set-aside" fields where weeds have not been controlled adequately.

The herbicides 2,4-D and Banvel (1 pt) plus 2,4-D (3 pt) are effective in controlling wild garlic if applied on corn or soybean stubble, grass pastures, and noncrop areas. The ester formulation of 2,4-D is more effective than the amine. Applications in early November after the majority of the garlic has emerged usually are the most effective. Spring applications also are effective if the temperature has been 60°F or higher for at least several days. This usually will be in mid- to late April, precluding the planting of soybeans on the treated acres. High rates of these herbicides applied in the spring also may cause corn injury if planting occurs soon after application.

In 1987, the herbicide Harmony (DPX-M6316) became available in Illinois and several other states under "emergency" state labels. A federal label was granted in 1988. Harmony is a postemergence herbicide that has a wider "window of application" than 2,4-D. It is highly effective in controlling wild garlic soon after the weed resumes active growth in the spring and is less affected by low temperatures than 2,4-D (Tables 1 and 2). Wheat is highly tolerant to Harmony regardless of the stage of the wheat at application if it is used according to label instructions (Table 2). Although Harmony does not always kill all of the wild garlic, it stunts it so severely that few of the aerial bulblets are harvested with the wheat. Harmony also affects the production of underground bulbs, but this greatly depends on the rate used, the time of application, and the year. Harmony has very little soil residual; thus, double-crop soybeans are not affected by the Harmony application. Refer to a current label for rates and additives to be used and for optimum time of application as well as recrop restrictions.

Harmony Extra, a 2:1 premix of Harmony and DPX-L5300, may replace Harmony for the 1990 use season. DPX-L5300 offers control of a wider range of broadleaf weeds that may infest wheat but is considered to be somewhat less effective on wild garlic. However, Harmony Extra has given essentially equal control of wild garlic compared to Harmony, unless application is delayed unduly (Table 2). Wheat is tolerant to Harmony Extra (Table 2), and double-crop soybeans may be planted following application. (Refer to label guidelines.)

One of the components of Preview, Lorox Plus, and Canopy is related chemically to Harmony. The use of one of these products as an "early preplant" application in early to mid-April preceding soybean planting has been observed to give some control or suppression of wild garlic. We have indicated that control during rotational crop years is vital if you hope to seriously reduce wild garlic populations. The use of one of these herbicides could be of substantial value in a comprehensive wild garlic control program at no additional cost to the grower.

If wild garlic has not been controlled adequately, it is virtually impossible to prevent harvesting some of the aerial bulblets. Carry the combine header as high as possible because the wild garlic usually is slightly shorter. The combine sieves and air volume should be adjusted as carefully as possible to remove as many of the bulblets as possible. However, it is very difficult to do a good job since most of the bulblets are about the same size and density as wheat kernels. It is possible to remove some of the bulblets after a period of storage. Wild garlic bulblets at harvest contain about 80 percent moisture. Following a storage period of 6 to 7 months, the moisture in the bulblets decreases enough so that air separation can remove some of them. Repeated drying of the grain with heated air would eliminate the need for the storage period.

Table 1. Influence of Harmony on Wild Garlic Aerial Bulblet Control and on Wheat Yield[a]

Herbicide[b]	Product rate	Year 1985	Year 1986	Year 1985	Year 1986
	oz/A	*bulblets/1,000 g*		*wheat yield bu/A*[c]	
None		94	10	35	44
2,4-D ester	24.00	34	6	38	34
Harmony	0.17	0	1	38	43
Harmony	0.33	0	0	36	43
Harmony	0.50	0	0	37	41
Harmony	0.67	0	0	39	39

[a]Located at Eldorado, Illinois, in 1985 and Cutler, Illinois, in 1986.
[b]All Harmony treatments included X-77 at 0.25 percent of the spray solution.
[c]No significant differences between treatments.

Table 2. Influence of Application Date and Rate of Harmony and Harmony Extra on Wild Garlic Aerial Bulblet Control and Wheat Yield[a]

Herbicide[b]	Product rate	Date of application, 1987[c] Mar. 20	Apr. 11	Apr. 30	Date of application, 1988[c] Mar. 23	Apr. 11	Apr. 30
	oz/A	*bulblets/1,000 g*			*bulblets/1,000 g*		
None		1,191	298	389		118	
2,4-D ester	32.00	26	106	103	12	7	7
Harmony	0.17	59	6	102	4	4	10
Harmony	0.33	2	1	66	3	8	1
Harmony	0.50	3	0	20	2	12	2
Harmony	1.00	2	1	2	1	1	0
Harmony Extra	0.17	52	16	15	5	0	11
Harmony Extra	0.33	5	2	1	0	2	3
Harmony Extra	0.50	1	4	5	0	4	0
Harmony Extra	1.00	1	2	2	1	0	3
		wheat yield, bu/A[c]			*wheat yield, bu/A*[c]		
None		52	58	64		73	
2,4-D ester	32.00	67	61	52	58	73	58
Harmony	0.17	68	62	61	77	68	67
Harmony	0.33	68	67	55	65	63	70
Harmony	0.50	67	61	60	66	70	66
Harmony	1.00	72	65	60	75	72	69
Harmony Extra	0.17	71	66	59	73	65	71
Harmony Extra	0.33	71	64	58	72	63	73
Harmony Extra	0.50	69	64	58	62	71	68
Harmony Extra	1.00	65	64	65	68	64	64

[a]Located at Lebanon, Illinois, in 1987 and DeSoto, Illinois, in 1988.

[b]All Harmony and Harmony Extra included X-77 at 0.25 percent of the spray solution.

[c]Wheat yield in the Harmony and Harmony Extra treatments was not significantly lower than the no-herbicide treatment at any application date in 1987 or 1988.

What Is New in Weed Control for 1989?

M. McGlamery

NEW HERBICIDES FOR CORN

Extrazine II will be the new name for the 3:1 ratio of cyanazine:atrazine formerly called Conquest. The old Extrazine, which was the 2:1 ratio of cyanazine:atrazine, will be dropped because of lack of profitability and too many products.

Bullet 4L is a microencapsulated formulation of 2.5 lb of alachlor (Lasso) and 1.5 lb of atrazine per acre. The ratio is the same as Lariat and the rates are similar. Encapsulation improves control in conservation tillage by reducing the volatility of alachlor. It also makes the formulation safer by removing some of the solvent effect seen with Lariat and Lasso.

Tough (pyridate) is a product from Terra that may be cleared in 1989 for postemergence use with atrazine for controlling broadleaves. A premix of pyridate and atrazine may be available.

Accent and *Beacon* are two experimental postemergence grass-control herbicides for use in corn. They will control shattercane and johnsongrass as well as most annual grass weeds. See "Postemergence Grass Control in Corn" by R. Liebl for more information.

NEW HERBICIDES FOR SOYBEANS

Postemergence Grass Herbicides

Assure 0.8E is a new postemergence herbicide that controls annual and perennial grasses in soybeans. Crop oil concentrate or a nonionic surfactant is needed. The rate of Assure varies with weed species, but is 10 to 16 fl oz per acre for annual grasses. Volunteer corn, shattercane, and seedling johnsongrass are more susceptible than foxtails (giant, green and yellow, and fall panicum). Rhizome johnsongrass and quackgrass require 20 fl oz/A and may require retreatment.

Select is a new postemergence grass herbicide for soybeans that will have an experimental use permit in Illinois in 1989. It is a chlorinated analogue of sethoxydim.

Postemergence Broadleaf Herbicides

Pinnacle 25DF will be a new postemergence herbicide for controlling broadleaf weeds, including pigweeds, smartweed, lambsquarters, and velvetleaf in soybeans. It is a short-life sulfonylurea that will have minimum recropping restrictions. Tank mixes with Classic will probably be cleared to improve cocklebur and morningglory control. Adjuvants such as surfactants are required for lambsquarters control, and velvetleaf control is improved with the use of 28 percent urea and ammonium nitrate (UAN).

Pursuit 2E (imazethapyr) will be a new postemergence herbicide for soybeans. The rate will be 0.25 pt (4 fl oz) or 1 oz of active ingredient per acre. It will control a large number of broadleaf weeds, including pigweed, jimsonweed, and velvetleaf. Probably, a surfactant or 28-0-0 UAN solution adjuvant will be called for.

Soil-Applied Premixes

Ala-Scept will be a premix of alachlor (Lasso) and imazaquin (Scepter) for preplant or preemergence use on soybeans. The formulation is being worked out, but the field rate will supply 2 lb of alachlor (equal to 2 qt of Lasso) and 0.125 lb of imazaquin (equal to 2/3 pt of Scepter).

Pursuit Plus is a premix of Pursuit and Prowl for preplant incorporation and preemergence use in soybeans. The use rate will supply 0.875 lb of pendimethalin (1.75 pt of Prowl) and 0.063 lb of imazethapyr (0.25 pt of Pursuit) per acre. Prowl will control grasses and the Pursuit will control many broadleaves, including velvetleaf and cocklebur.

Cannon 3EC is a 5:1 premix containing 2.5 lb of alachlor (Lasso) and 0.5 lb of trifluralin per gal for preplant incorporation in soybeans. It is labeled alone and in tank mix with all common broadleaf soybean herbicides. The common use rate will be 3 qt of Cannon per acre. It will primarily be targeted for dark-colored soils while Freedom will be targeted for light-colored soils.

Freedom 3EC is expected to be registered for use in soybeans in 1989. It contains 2.67 lb of alachlor and 0.33 lb of trifluralin per gal (8:1 ratio). It will be labeled alone and in tank mix with all common broadleaf soybean herbicides. The common use rate will be 1.5 to 2 qt/A.

NEW HERBICIDES FOR SET-ASIDE, CONSERVATION RESERVE PROGRAM, AND ALFALFA

Deploy was introduced in 1988 on a limited scale as a postemergence herbicide for annual weed control in set-aside. Deploy contains the active ingredient glyphosate (Roundup) without surfactant. In most cases, the recommended rate will be "Triple 12," that is, 12 fl oz of Deploy, 12 fl oz of 2,4-D, and 12 fl oz of surfactant in 10 gal of water. Banvel at 8 oz can be substituted for the 2,4-D.

Buctril is no longer restricted to strictly spring applications in seedling alfalfa. Alfalfa seedlings must have a minimum of two trifoliate leaves. If alfalfa is treated in the fall or winter, there is a 60-day restriction before it is used for grazing or cut for feed. Buctril can also be used for Conservation Reserve Program (CRP) land that is seeded to perennial ryegrass, fescues, and seedling alfalfa. Grasses must have reached the two- to three-leaf stage.

NEW CLEARANCES FOR 1989

Banvel clearance is expected for preharvest control of certain weeds such as hemp dogbane in corn and soybeans. The rate will probably allow up to 2 qt of Banvel per acre. Tank mixes with 2,4-D may also be cleared.

Dual was cleared in April 1988 in tank mixes with Scepter, Command, Preview, Lorox Plus, Gemini, and Canopy for application to soybeans.

Cobra should be cleared for tank-mixing with Basagran for 1989. The probable rate will be 10 to 12.5 fl oz of Cobra plus 1 pt of Basagran plus either crop oil concentrate or nonionic surfactant.

Scepter will have a clearance for a half-rate (1/3 pt/A) postemergence use in soybeans to allow reduced rotational restrictions. The current postemergence label has cocklebur, pigweed, and wild poinsettia on it.

Command has been cleared for use on pumpkins and succulent peas as well as on soybeans.

Management of Corn Rootworms: Research and Recommendations

K. Steffey, D. Kuhlman, K. Kinney, and M. Gray

The environmental circumstances of 1988 will be remembered for decades. The drought was the worst on record in the last 50 years, and the weather conditions had a disastrous effect on crops throughout the Midwest. However, because weather like that occurs only once every 50 years, researchers usually take the opportunity to collect data that would otherwise not be obtainable. Such was the case in 1988 with corn rootworm research and survey projects and with considerations for management of rootworms under unique circumstances.

The effects of the environmental conditions of 1988 on various aspects of corn rootworm biology and management are discussed in other papers in these *Proceedings*. Gerry Sutter addresses the effects of soil moisture on rootworm biology and control; Rick Weinzierl discusses the effects of environmental and crop conditions on making corn rootworm management decisions; and Karl Kinney presents rootworm soil insecticide evaluation data gathered in 1988.

This paper provides information about three other aspects of corn rootworms that we studied in 1988: (1) a survey to determine the size of rootworm beetle populations throughout the state and the distribution of the two rootworm species; (2) a survey of corn after soybeans to determine the extent of rootworm larval damage and the potential for extended diapause; and (3) a research project to study the interaction between rootworm larval damage and corn plant response as it is affected by corn variety, soil insecticides, and a plant growth regulator. The impact of the results of these studies on corn rootworm management for 1989 concludes this article.

CORN ROOTWORM BEETLE POPULATIONS IN 1988

In the midst of the hot, dry weather during July, many people encountered the largest number of corn rootworm beetles they had ever witnessed. Rootworm beetle emergence "exploded" in many fields of corn after corn over the July 4th weekend. Populations ranged from 10 to nearly 100 beetles per plant. The numbers were even more alarming because the beetles had emerged before pollination was completed. In addition, corn plants in many fields were undergoing different rates of development, so pollination was prolonged. This situation created concern about the effects of large numbers of rootworm beetles feeding on the silks over a long period of time and preventing successful pollination in fields already stressed by the drought.

The dilemma that confronted corn producers was not only *when* but *whether* to apply an insecticide for control of rootworm beetles to prevent silk clipping and subsequent reduced kernel set. The beetles were present in many fields before pollination had commenced, and they were feeding extensively on corn leaves, placing additional stress on the plants. However, we suggested that producers should wait until silks began to appear and then apply a spray only if the beetles were feeding on the newly emerging silks. Producers had to weigh factors of drought, delayed silk emergence, and bleak yield potential on their decision of whether or not to treat. Our rule-of-thumb recommendation was to treat when silk clipping was observed, pollination was not complete, and there were five or more rootworm beetles per plant. Rick Weinzierl discusses these decision-making criteria in his paper elsewhere in these *Proceedings*.

Rootworm beetle populations took a curious turn by mid-July. Several observers began finding a noticeable number of dead beetles in cornfields. This phenomenon continued into August. Joe Maddox, an insect pathologist at the Illinois Natural History Survey, suggested the most reasonable theory for the sudden death of rootworm beetles in Illinois cornfields. He examined a sample of dead beetles and found them to be "loaded" with bacteria. Rootworm beetles always have bacteria in the midgut, but under normal conditions these bacteria do not invade other portions of the body and are not pathogenic. However, under stress conditions (high temperatures, low-quality food source, and other factors) the bacteria invade the haemocoel (blood cavity) and are highly pathogenic. The beetles then die from bacterial septicemia. Although this is not an insect disease in the traditional sense, it is a "conditional disease" triggered by stressful conditions in the environment.

The results of our annual corn rootworm beetle survey are shown in Table 1. A graphic representation of rootworm beetle populations is shown in Figure 1. In each county listed, the surveyors counted the number of both western and northern corn rootworms on 20 plants selected at random in each of ten fields. The survey was conducted from July 28 through August 17, 1988, and the results bear out the low numbers of beetles other people were finding during this same time period. Obviously, the rootworm beetle populations "crashed" from their extremely high peaks in early and mid-July. Overall, the statewide average number of rootworm beetles per plant in 1988 was the lowest it has been since 1982.

It is important to note that the average number of rootworm beetles per plant in certain counties was relatively high compared with the averages obtained from most counties. However, the higher averages of 1.4, 2.7, 1.5, and 1.2 beetles per plant for Bureau, Mercer, Woodford, and Vermilion counties, respectively, were inflated by very high populations that were found in only one or two fields in the county. The surveyors found an average of 4.1 and 2.7 beetles per plant in two fields in Bureau County; 8.4 and 9.5 in two fields in Mercer County; and 3.7 in one field in Woodford County. The range in average number of beetles per plant in most counties simply reflects the disparity in attractiveness of different cornfields to rootworm beetles during their critical feeding and egg-laying period in the unusual summer of 1988. This information emphasizes the importance of scouting for rootworm beetles in each cornfield and making management decisions based on the information gathered from each field.

CORN ROOTWORM LARVAL DAMAGE IN CORN AFTER SOYBEANS IN ILLINOIS, 1988: EXTENDED DIAPAUSE?

We began randomly surveying fields of corn after soybeans for corn rootworm larval damage in 1986 after we received a few reports of damage occurring in this rotation. We suspected, but could not confirm, that extended diapause in the northern corn rootworm population was probably the cause of the damage where corn followed soybeans. The phenomenon of extended diapause (an extended period of arrested development in the egg stage) in northern corn rootworms had already been confirmed by entomologists in South Dakota, Minnesota, and Iowa (Krysan et al. 1986).

Because extended diapause represents a potential threat to the most effective means of controlling rootworms--that is, annual crop rotation between corn and soybeans--we have continued our surveys annually to determine whether the phenomenon has or will become entrenched in Illinois. Since 1986, we have surveyed 890 fields of corn after soybeans--300 fields in both 1986 and 1988 and 290 fields in 1987. The surveyors sampled ten fields of corn planted after soybeans in each of the counties selected for the survey. They randomly selected five plants in each field, dug them up, labeled them, and then returned them to Urbana for evaluation.

We used the Iowa State University rootworm damage rating scale of 1 through 6 (Hills and Peters 1971) to evaluate the root systems for different levels of damage caused by the larvae:

(1) No damage, or only a few minor feeding scars.

(2) Feeding scars evident, but no roots eaten off to within 1 1/2 inches of the plant.

(3) Several roots eaten off to within 1 1/2 inches of the plant, but never the equivalent of an entire node of roots destroyed.

(4) One node of roots completely destroyed.

(5) Two nodes of roots completely destroyed.

(6) Three or more nodes of roots destroyed.

A root rating of 1 indicates very little or no damage to the root system, and a root rating of 6 denotes extensive damage to the root system, characterized by severe pruning of the roots to within 1 1/2 inches of the stalk. A root rating of 3 or greater suggests a level of damage that will result in economic yield loss.

The results from the 1988 survey are presented in Table 2. Table 3 shows regional results from the surveys conducted during all three years. Approximately 94 percent of all root systems evaluated (state total) had a root rating of 1 or 2, indicating that rootworm damage to corn after soybeans in 1988 was infrequent (Table 2). This compares with 93.2 percent of the roots that had ratings of 1 or 2 in 1987 and approximately 97 percent in the same category in 1986. Only 6.4 percent of the roots sampled in 1988 had ratings of 3 or greater, compared with 6.2 percent in 1987 and 3.2 percent in 1986 (Table 3). The number of fields with an average root rating of 3 or greater has not increased significantly over the 3-year sampling period--2 (0.7 percent) in 1986, 4 (1.4 percent) in 1987, and 5 (1.7 percent) in 1988 (Table 3).

"Economic damage" (root rating greater than 3) to corn after soybeans has been found most frequently in the east and northeast regions of our survey (Tables 2 and 3). In 1988, the most startling results were obtained from Ford County in the east region (Table 2). Although 60 percent of the plants sampled had a root rating of 1 or 2, a significant proportion (28 percent) had a root rating of 3, and 12 percent of the roots rated 4 or greater. Twelve percent represents only 6 plants, a very small sample size, but that level of damage in corn after soybeans deserves further scrutiny.

CORN ROOTWORM LARVAL DAMAGE AND CORN PLANT RESPONSE

During our root-damage evaluations at Monmouth in July 1987, we observed an extreme level of root regrowth on many of the plants in our trial. The greatest amount of regrowth usually occurred on the root systems that had been severely damaged by rootworm larvae. It appeared that most of the damage had been done to the innermost nodes of roots (the first nodes to grow). Because rootworm egg-hatch occurred early in 1987, the nature of the damage to the earliest growing roots was not surprising. Regrowth around these damaged nodes obscured the amount of rootworm damage when the root system was first inspected. Many of these root systems had to be split in half with a knife in order to observe the extent of the damage. We also observed that the plants exhibiting a lot of regrowth had strong, upright stalks and apparently normally developing ears.

Because root regrowth is not accounted for in the standard 1-to-6 root rating scheme, we decided to collect additional data from this plot. Ten plants from each of seven treatment rows in each replication were dug, washed, and rated again in August. Each root system was marked individually so that measurements in addition to the root ratings could be made on the same plants. We measured the volume of each root system by using a water displacement technique. In October, we hand harvested 1/1,000 of an acre from each of the treatment rows for which we had a full complement of data.

The results of this preliminary study are presented in Table 4. The average root ratings in both July and August, the root volume, and the average yield are listed for each of the seven selected treatments. The data reveal that one "treatment" (actually an untreated check) that had substantial rootworm larval damage (average root rating of 5.6 in August) also had the largest average root volume (222 ml of water displaced) and the second highest yield (125 bushels per acre). Interestingly, the treatment with the lowest average root rating (1.8 in August) had the lowest average root volume (187 ml of water displaced) but the highest yield (128 bushels per acre). These data suggest that corn plants have the capacity to compensate for rootworm larval damage and to produce a yield equivalent to the yield in plots treated with insecticides, even under the rather dry soil conditions that occurred at Monmouth in 1987. We also detected a hint that the insecticide used might influence the amount of compensation that the corn plant expresses.

Overall, we concluded from these preliminary data that simple root ratings based on the Iowa State 1-to-6 scale could not adequately represent subsequent yield responses under certain conditions. This conclusion has been supported recently by research conducted by Sutter et al. (1986). Most entomologists now believe that the relationship between rootworm larval damage and subsequent yield is not clearcut; it is probably influenced by the ability of the corn variety to compensate for damage, environmental conditions, the presence or absence of certain insecticides, and several other factors.

In 1988, we undertook a more rigorous research project to elucidate the relationship between rootworm larval damage and subsequent yield. The research is a cooperative effort with Emerson Nafziger in the Department of Agronomy. We used a split-split plot design to examine the influence of two corn varieties, three insecticide treatments (including an untreated check), and a plant growth regulator on this complex relationship. The experiment was conducted in Champaign County at the ICI Americas Research Farm and in DeKalb County at the University of Illinois Northern Agronomy Research Farm.

The two corn varieties selected for our trial were Pioneer 3377 and Pioneer 3378. These two varieties are purported to respond differently under certain environmental conditions. Pioneer 3377 is a so-called "racehorse" variety that produces high yields under optimum conditions but doesn't always respond well under stressful environmental conditions. Pioneer 3378 is a "workhorse" variety with the ability to produce reasonable yields even under stressful conditions.

Counter 15G, Lorsban 15G, and an untreated check were tested within each main block (variety). Cerone 4L (ethaphon) is a plant growth regulator that produces ethylene. This product has been used to enhance wheat yields and has been tested to determine its effects on corn growth and yield. Results from research conducted in Illinois have shown that Cerone reduces cell elongation and expansion so that stem growth is temporarily inhibited. The result is a shorter plant that may eventually attain normal height. Application of Cerone also causes a temporary surge in available carbohydrates, so more brace roots and overall root growth can usually be expected. Finally, depending on the rate applied, Cerone often reduces corn yield (Lechtenberg 1988).

The plots were planted on May 4 and May 5, 1988, at Champaign and DeKalb, respectively. The two corn varieties and three insecticide treatments were established within the two trials according to specific plot designs. Each main plot effect (corn variety) was replicated four times in a randomized complete block design. The insecticide treatments were replicated within each main plot effect in each replication.

Each corn variety x insecticide treatment was further split so that one-half of the treatment received an application of Cerone and the other half was not treated. Cerone 4L was applied at 1/8 pound of active ingredient per acre on June 16 and June 17, 1988, at Champaign and DeKalb, respectively. Cerone was banded over the center two rows of each designated four-row plot to avoid drift to neighboring plots. At the time of application, the corn was in the eight- to nine-leaf stage at both locations.

Evaluation of these two trials was rather extensive. Stand counts were taken on May 26 at Champaign and June 2 at DeKalb. In mid-July, several parameters were evaluated at each location. Ten plants were dug from each treatment, and the plants were thoroughly washed and then rated for rootworm larval damage using the Iowa State 1-to-6 root rating scale described previously in this paper. Each root system was also given a recovery rating based on the scale proposed by Hills and Peters (1971):

(0) No apparent recovery.

(1) Four to six roots on the top node showing regrowth.

(2) Top ring of roots all showing some regrowth.

(3) Considerable secondary roots and complete node of regrowth.

(4) Regrowth on more than one node and good secondary development.

The rating derived from this scale was then subtracted from the original root-damage rating to determine an adjusted root rating that accounted for compensatory root growth. Each root system was then dipped into a pre-determined amount of water so that the volume of water displaced could be measured as an estimate of root volume.

These root evaluations were repeated for five plants from each treatment in early August. In addition, stalk circumference was measured just below the first node above ground level. In October, we hand harvested 1/1,000 of an acre from each of the treatment rows to estimate the yield from each plot.

At the time this manuscript was written, the data gathered from these plots had not been thoroughly analyzed. Stand count data, stalk circumference, and yield are not presented here but will be discussed during the conference presentation. Mean root ratings, recovery ratings, adjusted root ratings, and estimated root volumes from both trials are presented in Tables 5 and 6. Statistical comparisons among these means had not been completed, so only the raw means are provided. The data for both dates of evaluation are presented so that changes that occurred over time can be examined.

Rootworm larval damage was severe in the untreated check plots at both Champaign (Table 5) and DeKalb (Table 6). It should be noted that the soil at the Champaign location was drier throughout much of the study period than it was at DeKalb. This might explain the obvious differences in root ratings between plots treated with Counter and those treated with Lorsban. At Champaign, where the soil was extremely dry, Lorsban-treated plots had significantly higher root ratings than Counter-treated plots. At DeKalb, the differences in root ratings between Counter- and Lorsban-treated plots were not as dramatic. Lorsban, a relatively insoluble compound, usually provides better root protection when soil moisture is not a limiting factor.

Because much more extensive analyses are necessary to fully comprehend these data, sweeping conclusions can not yet be drawn. However, initial analysis of variance revealed that in the Champaign plot, significant differences in root ratings, adjusted root ratings, and root volume measured in both July and August occurred between the two varieties and among the three insecticide treatments. There was also a significant interaction between variety and insecticide for root ratings and adjusted root ratings in July. Cerone significantly influenced root volume measured in July, but the significance had disappeared by the time of the August evaluation. There were no significant interactions between variety and Cerone, insecticide treatment and Cerone, or variety x insecticide treatment x Cerone in July. However, a significant interaction between Cerone and insecticide treatment occurred in August.

In the DeKalb plot, significant differences in root ratings, adjusted root ratings, and root volume measured in July occurred between the two varieties and among the three insecticide treatments. There were significant interactions between variety and insecticide treatment for adjusted root ratings and for root volume. Cerone also significantly influenced adjusted root ratings and root volume in July. In addition, there was a significant interaction between Cerone and insecticide treatment for adjusted root ratings. However, almost all of these significant differences and interactions disappeared by the time evaluations were made in August. Only significant differences in root ratings and adjusted root ratings among the three insecticide treatments were apparent in August.

Probably the most telling data are the adjusted root ratings for the August evaluations and the change in root volume that occurred between July and August. Both of these sets of data reveal the ability of both corn varieties to compensate for rootworm larval damage by growing secondary and brace roots, even in the untreated check plots. Only the yield data will reveal if the plants compensated enough to produce equivalent yields among the different treatments.

It is interesting to note that the adjusted root ratings were considerably lower at DeKalb than at Champaign. Again, soil at the Champaign location was quite dry throughout the course of the study. Available moisture at DeKalb might have helped promote more compensatory root growth, allowing for lower adjusted root ratings.

We also found that the influence of Cerone on the parameters measured was only temporary in nature. At this point, it seems that Cerone, applied at the rate we used, cannot be suggested as a treatment to promote lasting effects in root growth compensation.

These data must be thoroughly scrutinized if we are to draw any rational conclusions that suggest a complex relationship between corn rootworm larval damage and subsequent yield. In addition, some of the same experimentation was conducted at Iowa State University in 1988 by Barbara Spike, a graduate student working for Jon Tollefson. Her data will be examined critically in comparison with our results to determine if identifiable trends exist. Finally, Spike's research regarding the influence of fertility level and plant population on this complex relationship (Spike and Tollefson 1988) will also be considered as we attempt to solve this puzzle.

IMPACT OF THE RESULTS OF OUR 1988 STUDIES ON CORN ROOTWORM MANAGEMENT FOR 1989

Not all of what we found in 1988 will have direct application to suggestions for corn rootworm management in 1989. However, some predictions and comments about the future direction of corn rootworm research and management can be made.

Corn Rootworm Beetle Populations in 1988

The relatively low numbers of beetles found in cornfields during late July and early August 1988 suggest that the potential for rootworm larval damage in 1989 should be lower than usual. However, extremely high populations were found in some fields, so rootworm control decisions in any given field in 1989 should ideally be based on the number of rootworm beetles found in 1988.

Other questions also complicate our predictions for 1989. Did female rootworm beetles survive long enough in 1988 to lay a full complement of eggs before they perished from bacterial septicemia? Did stress caused by high temperatures and poor quality food reduce the fecundity of the females? If female beetles produced eggs, were suitable egg-laying sites available? Female rootworms prefer to lay their eggs in loose, moist soil; much of the soil was extremely dry in 1988. If the female beetles found suitable egg-laying sites, how deep did they have to go to find moisture? Females often travel down drought cracks seeking a level of moisture in the soil. If the females laid their eggs deep in the soil, how will these eggs survive the winter? How will the survival of the eggs over the winter be influenced by tillage operations? Finally, how will environmental conditions during the 1988-1989 winter affect the survival of rootworm eggs?

The odds are that low numbers of rootworm beetles, lower fecundity of female beetles due to stress, and a lack of suitable egg-laying sites will interact to lower the potential for rootworm problems in 1989. However, unless a grower has excellent records of rootworm beetle numbers over several weeks of the 1988 summer, this prediction is not as reliable. As a consequence, crop rotation to a nonhost crop or the use of a soil insecticide for corn after corn will still be the management techniques of choice.

Rootworm Larval Damage in Corn after Soybeans

The percentage of fields of corn following soybeans in which rootworm larval damage was found in 1988 remained relatively unchanged from that found in 1987, and it has remained relatively low for 3 years. There is not sufficient evidence to suggest that extended diapause has become entrenched in Illinois, threatening our most reliable rootworm management technique, crop rotation. Given the very few instances of rootworm damage to corn after soybeans, we believe there is little justification for wholesale application of soil insecticides to corn after soybeans to prevent rootworm damage. However, certain fields in eastern and northeastern Illinois have been sufficiently damaged by rootworm larvae that surveys in those areas should be intensified to determine if extended diapause might become a management concern in the near future.

Continued surveillance for rootworm larval damage in corn after soybeans is the only way growers can detect the development of a problem. If the extended diapause problem does develop in Illinois, then our management suggestions will have to be adjusted accordingly. Until that time, we still believe that crop rotation is a very viable option for rootworm management.

Rootworm Larval Damage and Corn Plant Response

It is still much too early to formulate suggestions for rootworm management based on the preliminary data gathered to date. However, it is quite apparent that different corn varieties respond differently to rootworm larval damage and that the plants' response is influenced by several other factors, including environmental conditions, soil insecticide, fertility level, and plant population. Although Cerone did not seem to have a significant effect on our results in 1988, further testing at different rates and under different conditions might reveal some trends. We will continue this work so that we can better inform growers in the future about the prospects for economic levels of rootworm damage under different environmental and cultural conditions.

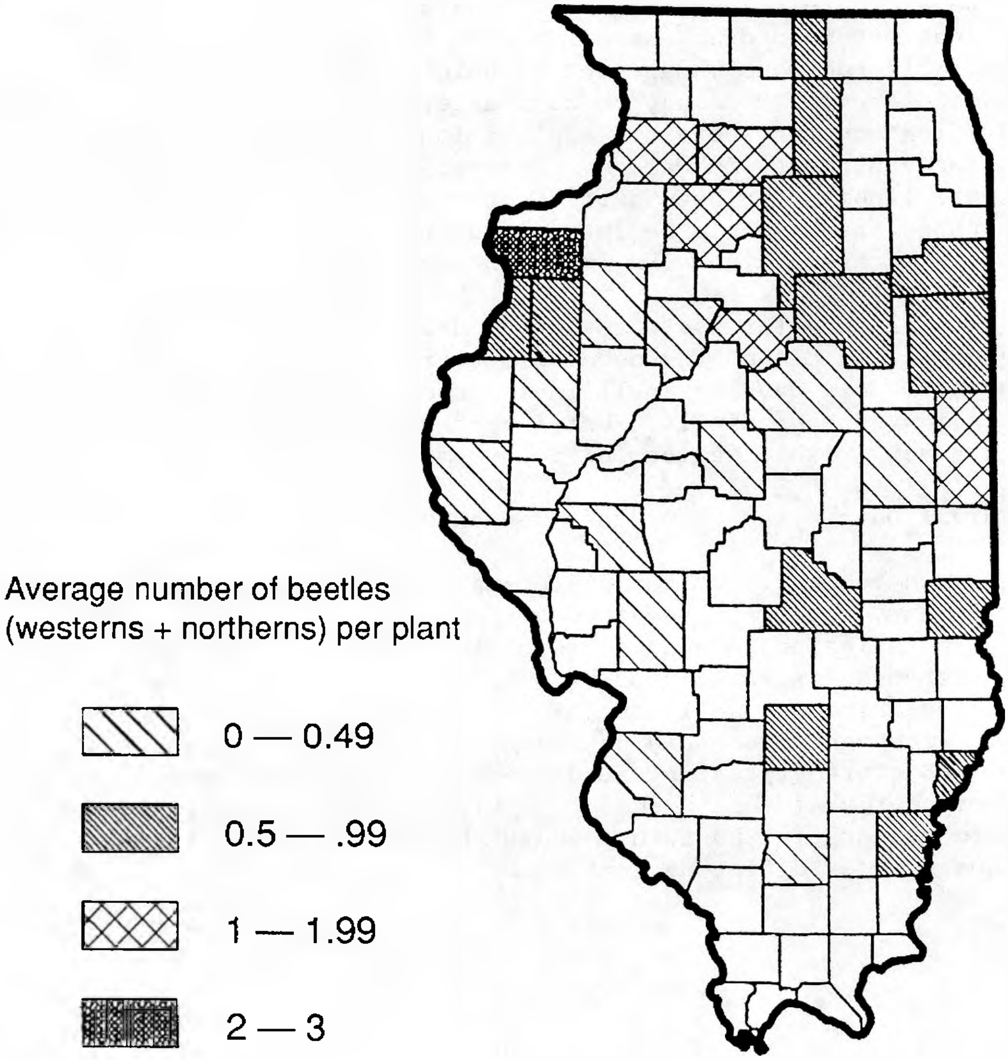

Figure 1. Corn rootworm beetle populations in Illinois, 1988.

Table 1. A Survey of Corn Rootworm Beetles in Illinois Corn, 1988

Region and county	Average number of beetles per plant[a]			
	Western corn rootworm	Northern corn rootworm	Total	Range[b]
Northwest				
Bureau	1.36	0.05	1.4	0.35-4.10
Henderson	0.80	0.02	0.8	0.05-2.05
Knox	0.16	0.01	0.2	0.00-0.65
Lee	0.60	0.38	1.0	0.65-1.40
Mercer	2.72	0.00	2.7	0.00-9.45
Warren	0.83	0.01	0.8	0.00-4.15
Whiteside	0.65	0.34	1.0	0.55-1.45
Northeast				
Boone	0.73	0.09	0.8	0.00-2.95
DeKalb	0.47	0.13	0.6	0.25-1.00
Kankakee	0.32	0.27	0.6	0.30-0.90
LaSalle	0.18	0.47	0.7	0.00-2.85
Livingston	0.34	0.14	0.5	0.10-0.70
West				
Adams	0.11	0.00	0.1	0.00-0.25
Macoupin	0.26	0.00	0.3	0.00-1.00
McDonough	0.22	0.00	0.2	0.05-0.95
Morgan	0.09	0.01	0.1	0.00-0.30
Central				
Logan	0.16	0.01	0.2	0.05-0.35
McLean	0.11	0.23	0.3	0.05-1.00
Peoria	0.12	0.06	0.2	0.00-1.05
Shelby	0.53	0.25	0.8	0.15-1.35
Woodford	0.96	0.54	1.5	0.05-3.70
East				
Champaign	0.21	0.17	0.4	0.10-0.65
Clark	0.38	0.11	0.5	0.20-0.80
Iroquois	0.42	0.12	0.5	0.15-1.00
Vermilion	0.91	0.27	1.2	0.75-1.35
South				
Franklin	0.31	0.07	0.4	0.05-0.70
Marion	0.41	0.17	0.6	0.25-1.10
St. Clair	0.03	0.00	0.03	0.00-0.20
Wabash	0.61	0.13	0.7	0.25-1.35
White	0.68	0.18	0.9	0.15-2.20

[a]Averages based on samples from 10 fields per county, 20 plants per field.
[b]Ranges are the lowest average number of beetles per plant to the largest average number of beetles per plant from a sample of 10 fields in one county.

Table 2. A Survey of Corn Rootworm Larval Damage in Corn Following Soybeans in Illinois, 1988

Region and county	Number of fields surveyed	Average root rating per field	Percent of plants by root rating						Average number of fields by root rating (range)		
			1	2	3	4	5	6	1.0-1.9	2.0-2.9	>3.0
West	*40*	*1.14*	*87.5*	*11.0*	*1.5*	*0*	*0*	*0*	*39*	*1*	*0*
Adams	10	1.12	92	4	4	0	0	0	9	1	0
Hancock	10	1.12	88	12	0	0	0	0	10	0	0
Knox	10	1.18	82	18	0	0	0	0	10	0	0
McDonough	10	1.14	88	10	2	0	0	0	10	0	0
Central	*70*	*1.47*	*61.1*	*31.4*	*6.3*	*1.1*	*0*	*0*	*54*	*14*	*2*
DeWitt	10	1.3	70	30	0	0	0	0	10	0	0
Macon	10	1.26	74	26	0	0	0	0	10	0	0
Marshall	10	1.9	34	50	8	8	0	0	5	4	1
McLean	10	2.06	18	58	24	0	0	0	0	10	0
Logan	10	1.44	58	40	2	0	0	0	10	0	0
Sangamon	10	1.04	96	4	0	0	0	0	10	0	0
Tazewell	10	1.32	78	12	10	0	0	0	9	0	1
Northwest	*50*	*1.25*	*76.8*	*21.6*	*1.6*	*0*	*0*	*0*	*46*	*4*	*0*
Bureau	10	1.32	68	32	0	0	0	0	9	1	0
Lee	10	1.38	68	26	6	0	0	0	8	2	0
Mercer	10	1.18	82	18	0	0	0	0	10	0	0
Ogle	10	1.22	78	22	0	0	0	0	10	0	0
Whiteside	10	1.14	88	10	2	0	0	0	9	1	0

Table 2. *(continued)*

Region and county	Number of fields surveyed	Average root rating per field	Percent of plants by root rating						Average number of fields by root rating (range)		
			1	2	3	4	5	6	1.0-1.9	2.0-2.9	>3.0
Northeast	*70*	*1.61*	*50.3*	*39.7*	*8.9*	*0.9*	*0.3*	*0*	*49*	*20*	*1*
Boone	10	1.04	96	4	0	0	0	0	10	0	0
Grundy	10	1.86	26	62	12	0	0	0	6	4	0
Kane	10	1.42	62	34	4	0	0	0	8	2	0
Kendall	10	1.96	20	64	16	0	0	0	5	5	0
LaSalle	10	1.66	44	48	6	2	0	0	7	3	0
McHenry	10	1.12	88	12	0	0	0	0	10	0	0
Will	70	2.2	16	54	24	4	2	0	3	6	1
East	*70*	*1.53*	*56.6*	*35.4*	*6.3*	*1.4*	*0.3*	*0*	*53*	*15*	*2*
Champaign	10	1.34	66	34	0	0	0	0	10	0	0
Ford	10	2.48	6	54	28	10	2	0	0	8	2
Iroquois	10	1.26	78	18	4	0	0	0	9	1	0
Kankakee	10	1.58	48	46	6	0	0	0	7	3	0
Livingston	10	1.52	50	48	2	0	0	0	9	1	0
Piatt	10	1.12	88	12	0	0	0	0	10	0	0
Vermilion	10	1.44	60	36	4	0	0	0	8	2	0
STATE TOTAL	*300*	*1.44*	*63.7*	*29.9*	*5.5*	*0.8*	*0.1*	*0*	*241*	*54*	*5*
									80.3%	*18.0%*	*1.7%*

Table 3. A Random Survey of Corn Rootworm Damage in 890 Fields of Corn after Soybeans, Illinois, 1986-1988

Region	Number of fields surveyed per year			Average root rating/field			Percent of plants with root ratings 3.0 or greater			Number of fields with root ratings 3.0 or greater		
	1986	1987	1988	1986	1987	1988	1986	1987	1988	1986	1987	1988
West	40	40	40	1.1	1.5	1.1	0	3.5	1.5	0	0	0
Central	70	70	70	1.3	1.5	1.5	2.3	8.0	7.4	0	2	2
Northwest	50	40	50	1.2	1.2	1.3	1.6	2.0	1.6	0	0	0
Northeast	70	70	70	1.5	1.6	1.6	8.9	8.9	10.1	1	1	1
East	70	70	70	1.3	1.6	1.5	3.4	8.6	8.0	1	1	2
Total	300	290	300	...	...	...	...	...	...	2	4	5
Average				1.3	1.5	1.4	3.2	6.2	6.4	0.7%	1.4%	1.7%

Table 4. Rootworm Larval Damage and Yield, Monmouth, Illinois, 1987

Average root rating (July)	Average root rating (August)	Volume of water displaced (ml)	Average yield (bu/A)
1.9	1.8	187	128
2.1	2.3	204	113
2.9	2.5	205	114
2.9	2.9	208	113
4.0	3.3	211	117
5.4	5.6	222	125
6.0	5.8	197	109

Table 5. Response of Two Corn Varieties to Rootworm Larval Damage as Influenced by Insecticides and Cerone, Champaign County, IL, 1988

Variety	Treatment	Mean root rating[a] (7/14) Cerone	Mean root rating[a] (7/14) No Cerone	Mean root rating[b] (8/7) Cerone	Mean root rating[b] (8/7) No Cerone
3377	Counter	2.59	2.94	2.40	3.05
	Lorsban	4.08	3.87	4.35	3.95
	Check	5.47	5.42	5.50	5.20
3378	Counter	2.65	2.62	2.55	2.70
	Lorsban	3.27	3.30	3.75	3.15
	Check	4.72	4.72	4.80	4.80

Variety	Treatment	Adj. root rating[c] (7/14) Cerone	Adj. root rating[c] (7/14) No Cerone	Adj. root rating[d] (8/7) Cerone	Adj. root rating[d] (8/7) No Cerone
3377	Counter	2.24	2.51	1.65	2.45
	Lorsban	3.08	2.97	2.85	2.35
	Check	4.92	5.03	3.75	3.95
3378	Counter	2.33	2.22	1.70	2.10
	Lorsban	2.20	2.72	1.85	2.00
	Check	3.97	4.12	3.35	3.50

Variety	Treatment	Root volume[e] (7/14) Cerone	Root volume[e] (7/14) No Cerone	Root volume[f] (8/7) Cerone	Root volume[f] (8/7) No Cerone
3377	Counter	102.9	86.3	146.0	126.3
	Lorsban	81.9	70.6	105.0	112.5
	Check	46.3	46.8	101.3	86.3
3378	Counter	97.5	85.0	130.0	130.0
	Lorsban	103.0	77.5	145.0	122.5
	Check	75.0	67.5	111.3	103.8

[a]Means based on ten observations per treatment per replication. Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6).
[b]Means based on five observations per treatment per replication. Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6).
[c]Means based on ten observations per treatment per replication. Adjusted root rating is derived by subtracting a recovery rating ranging from no root recovery (0) to extensive root recovery (4) from the initial root damage rating.
[d]Means based on five observations per treatment per replication. Adjusted root rating is derived by subtracting a recovery rating ranging from no root recovery (0) to extensive root recovery (4) from the initial root damage rating.
[e]Means based on ten observations per treatment per replication. Root volume estimated by displacing a measured volume of water.
[f]Means based on five observations per treatment per replication. Root volume estimated by displacing a measured volume of water.

Table 6. Response of Two Corn Varieties to Rootworm Larval Damage as Influenced by Insecticides and Cerone, DeKalb County, IL, 1988

Variety	Treatment	Mean root rating[a] (7/13) Cerone	Mean root rating[a] (7/13) No Cerone	Mean root rating[b] (8/8) Cerone	Mean root rating[b] (8/8) No Cerone
3377	Counter	2.20	2.05	2.25	2.25
	Lorsban	2.37	2.75	2.70	2.70
	Check	4.70	4.75	5.15	4.70
3378	Counter	2.20	2.17	2.15	2.20
	Lorsban	2.80	2.90	2.90	3.00
	Check	4.95	5.27	5.15	4.90

Variety	Treatment	Adj. root rating[c] (7/13) Cerone	Adj. root rating[c] (7/13) No Cerone	Adj. root rating[d] (8/8) Cerone	Adj. root rating[d] (8/8) No Cerone
3377	Counter	1.72	1.67	1.05	1.15
	Lorsban	1.57	2.10	1.05	1.15
	Check	2.59	3.00	2.75	2.45
3378	Counter	1.67	1.90	1.25	1.40
	Lorsban	1.97	2.22	1.50	1.20
	Check	3.65	4.50	2.75	2.90

Variety	Treatment	Root volume[e] (7/13) Cerone	Root volume[e] (7/13) No Cerone	Root volume[f] (8/8) Cerone	Root volume[f] (8/8) No Cerone
3377	Counter	105.0	96.9	177.5	173.8
	Lorsban	131.9	96.9	190.0	178.8
	Check	115.0	99.6	168.8	205.0
3378	Counter	116.9	106.3	143.8	151.3
	Lorsban	124.4	103.3	137.5	156.3
	Check	76.3	42.1	180.0	143.8

[a]Means based on ten observations per treatment per replication. Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6).
[b]Means based on five observations per treatment per replication. Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6).
[c]Means based on ten observations per treatment per replication. Adjusted root rating is derived by subtracting a recovery rating ranging from no root recovery (0) to extensive root recovery (4) from the initial root damage rating.
[d]Means based on five observations per treatment per replication. Adjusted root rating is derived by subtracting a recovery rating ranging from no root recovery (0) to extensive root recovery (4) from the initial root damage rating.
[e]Means based on ten observations per treatment per replication. Root volume estimated by displacing a measured volume of water.
[f]Means based on five observations per treatment per replication. Root volume estimated by displacing a measured volume of water.

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The Illinois Insecticide Evaluation Program: Results of Field Trials with Black Cutworms, Corn Rootworms, and European Corn Borers

K. Kinney, K. Steffey, and D. Dazey

In 1985, the Illinois Natural History Survey's (INHS) Section of Economic Entomology reorganized and expanded its insecticide evaluation research efforts. The resulting program is coordinated by a research biologist who works closely with Extension entomology specialists at the University of Illinois and with INHS research scientists to plan and carry out insecticide and other insect control evaluations. The audience that benefits from this program consists of growers, scientists, educators, consumers, and representatives of industry.

The current Illinois Insecticide Evaluation Program (IIEP) has a service-oriented approach. It offers unbiased evaluations and comparisons of insecticide products. It also provides the resources and personnel for addressing other important research needs related to insecticides and the management of insect pests. Results, many of which are immediately applicable, are reported annually to interested clientele in Illinois and throughout the nation. In addition to compiling efficacy data, researchers become familiar with and report on many practical concerns associated with both registered and experimental products. Observations on calibration, mixing, and application methods for different products are important portions of the project's annual report.

Research conducted from 1985 through 1988 has been directed primarily to the evaluation of products and application techniques used to control the major economic insect pests of field and forage crops in Illinois. Besides traditional methods of insecticide application, researchers have made an effort to study more appropriate types of placement and different times of application to improve efficacy or reduce environmental contamination and the hazard to nontarget organisms.

Annually, between 4 and 5 million acres of "continuous" corn in Illinois are treated with a planting-time insecticide to control the larval stages of western and northern corn rootworms, *Diabrotica* spp. Studies have been conducted throughout the state to evaluate control of corn rootworms with both registered and experimental insecticides and with biological "insecticides." Two biological organisms, *Beauveria bassiana*, a fungus, and *Steinernema feltiae*, an entomogenous nematode, have been examined as potential alternatives for control of corn rootworms. Other studies have focused on control strategies for the black cutworm, *Agrotis ipsilon*, and for the first and second generations of the European corn borer, *Ostrinia nubilalis*, both major pests of field corn.

Researchers also have evaluated insecticides applied to control the potato leafhopper, *Empoasca fabae*, and the alfalfa weevil, *Hypera postica*, the two most significant pests of alfalfa in Illinois. In these studies, observers have assessed not only the mortality of the pest species, but also the insecticides' impact on predators and parasitoids that influence pest populations in alfalfa fields. Reduced application rates of insecticides that control pests without harming beneficial insect populations have also been studied.

Most of the evaluations carried out in this project have been conducted under conditions similar to those confronting Illinois producers. In order to establish large-scale field trials and demonstration plots, investigators have cooperated with farmers, aerial applicators, industry representatives, Extension integrated pest management (IPM) advisers, and University of Illinois Agronomy Research Centers. When needed, conventional equipment is used for planting, cultivating, and harvesting, and for making specialized pesticide applications. Most of this equipment is modified so that scientists can establish smaller-scale research plots as well. The specialized modifications to our field equipment provide flexibility for our research efforts and are important technical resources for the IIEP.

Insecticides are important components in current crop production systems. The IIEP provides up-to-date information on insecticides and application techniques. The data help producers select and use appropriate insecticides only when necessary so that valuable crops can be grown economically and with a minimum level of adverse effects to human safety and the environment. The IIEP also offers the framework to address future research needs and management options in areas such as low-input sustainable agriculture and the use of bioengineered microorganisms and plants for insect control.

RESULTS OF FIELD TRIALS WITH BLACK CUTWORMS, CORN ROOTWORMS, AND EUROPEAN CORN BORERS

During 1988, researchers from the INHS, cooperating with Extension specialists and researchers from the University of Illinois, conducted many field trials throughout Illinois. However, only portions of these investigations are reported in this paper. For those who wish to have more detailed information, a complete report entitled "Illinois Insecticide Evaluations--Field and Forage Crops 1988" is available through the INHS Section of Economic Entomology.

Black Cutworms

Methods. Field trials were established at the University of Illinois Pomology Farm, Urbana, Illinois, to compare registered and experimental insecticides as preventative and rescue treatments for control of black cutworm (BCW) larvae. Corn was planted on May 31, 1988, on 30-inch centers with a 4-row John Deere 7000 series planter. Each plot consisted of four rows of corn 50 feet long. The experimental design was a randomized complete block with six replications. Because of the difficulty in predicting and establishing a natural cutworm infestation, we used laboratory-reared BCW larvae to infest corn plots enclosed within barriers that prevented the cutworms from escaping.

Preplant-incorporated (PPI) treatments were applied immediately prior to planting and were incorporated in the upper 2 inches of soil with one pass of a disk; preemergence (PRE) treatments were applied on June 3, 1988; rescue treatments were applied on June 11, 1988, about 36 hours after the first batch of cutworms was introduced into the plots. All PPI, PRE, and rescue treatments were broadcast. A 10-foot boom was mounted by a 3-point hitch to the rear of a 3020 John Deere tractor (boom height 17 inches above the ground). XR8004 (Spraying Systems) flat fan nozzles were spaced 20 inches apart on the boom. A compressed air system was calibrated to deliver 21.0 gallons per acre (gpa) at a pressure of 40 pounds per square inch (psi) at a speed of 3 miles per hour (mph). To apply rescue treatments without disturbing the barriers, we offset the boom by 12 feet to the side of the tractor. At-planting liquids were applied in a 10-inch band at 40 psi in 43.3 gpa, using 8002E (Spraying Systems) even-flat fan nozzles at a speed of 5 mph.

Granular insecticides applied at planting were metered through Noble units mounted on the middle two planter units. Granules were applied in furrow or in a 7-inch band ahead of the firming wheels on the planter. Spring tines were used to incorporate the insecticides into the soil at planting. Seed treatments to be evaluated for cutworm control were mixed with seed on the day of planting, and the treated seeds were planted in the appropriate plots.

After corn plants had reached the one-leaf stage, a 6-ft^2 barrier was placed over a portion of the middle two rows of each plot. The barriers were sunk to a depth of 1 inch, and dirt was tamped around the sides to reduce the possibility of cutworm escape. Five fourth to fifth instar black cutworm larvae were placed in each barrier on June 10, 1988, and an additional five were added to each barrier on June 11, 1988.

Evaluations. On June 9, 1988, before the plots were infested with BCW larvae, the total number of plants growing within each barrier was recorded. On June 10, 11, 13, 15, 17, and 21, 1988, the numbers of cut plants per barrier were recorded. Values for the number of cut plants and the percentage of cut plants per barrier are reported as cumulative means.

Results and Discussion. Only 0.25 inch of rain fell on the plots throughout the study period. This low amount of precipitation was accompanied by unusually high temperatures. Fortunately, the rain that was recorded occurred 2 days prior to the introduction of the cutworm larvae. As a result, cooler temperatures were present during the first couple of days of cutting activity. While this created a suitable environment for the cutworms, the high temperatures and lack of moisture seemed detrimental to the performance of some insecticide treatments in this test.

The results of the evaluation of preventative insecticides for control of BCW larvae are presented in Table 1. Except for the low rate of ICI's Karate 1WG, both Karate 1E and Karate 1WG significantly reduced the level of cutting when compared to the level of cutting in the untreated check. It should be noted that the PRE treatments of Karate were applied 3 days closer to the time of the introduction of cutworms than were any of the other preventative treatments. In light of this, it is difficult to determine whether Karate is a superior cutworm product or whether the timing of these applications helped this product avoid the detrimental environmental effects that persisted through the duration of the trial. Although several other products numerically reduced the level of cutting, none were statistically different from the untreated check.

Several products that have performed well in our cutworm trials in the past were ineffective in this test, probably due to unfavorable weather conditions. The two most notable products that performed more poorly than in past trials were ICI's Force 1.5G and DuPont's Fortress 10G. It is interesting to note that plots treated with Fortress 10G applied in furrow had less cutting activity than plots treated with Fortress 10G applied in a 7-inch band. This response is exactly the opposite of what we observed in 1987 under more typical growing conditions. It seems likely that in-furrow applications reduced the volatilization of Fortress and afforded protection for a longer period of time than the band applications.

Dow's XRD-522 0.9EC, when applied as a PPI treatment, was ineffective at reducing the level of cutting when compared with the level of cutting in the untreated check.

Table 1. Evaluation of Preventative Insecticide Treatments for Control of Black Cutworms, Spring Barrier Study, University of Illinois Pomology Farm, Urbana, Champaign County, Illinois, 1988

Product	Rate*	Method of application	Mean number plants cut per barrier**	Mean percentage plants cut
Karate 1WG	0.025 lb a.i.***	PRE****	1.00 e	6.4
Karate 1E	0.02 lb a.i.***	PRE****	1.17 de	6.7
Karate 1E	0.025 lb a.i.***	PRE****	1.50 c-e	8.8
Karate 1WG	0.02 lb a.i.***	PRE****	2.17 b-e	12.4
Lorsban 15G	8.0 oz	7-in. band	2.33 b-e	13.2
Pounce 1.5G	0.1 lb a.i.***	7-in. band	2.60 b-e	15.3
Fortress 10G	6.0 oz	furrow	2.67 b-e	15.7
E 4242 10G	6.7 oz	7-in. band	2.83 b-e	17.9
Pounce 3.2EC	0.1 lb a.i.***	PRE****	3.00 b-e	18.0
E 4242 10G	9.0 oz	furrow	3.50 b-e	19.5
XRD-522 .9EC	0.019 lb a.i.***	10-in. band*****	3.67 b-e	20.1
Aastar 15G	8.0 oz	7-in. band	4.17 b-e	23.4
Dyfonate 20GM	6.0 oz	7-in. band	4.17 b-e	24.4
Counter 15G	8.0 oz	furrow	4.33 b-d	25.6
XRD-522 .9EC	0.015 lb a.i.***	10-in. band*****	4.33 b-d	23.7
E 4242 10G	4.5 oz	7-in. band	4.40 b-d	25.2
Counter 15G	8.0 oz	7-in. band	4.50 bc	24.5
Force 1.5G	8.0 oz	7-in. band	4.50 bc	25.3
Fortress 10SRG	6.0 oz	7-in. band	4.80 b	25.9
Fortress 10G	6.0 oz	7-in. band	5.17 ab	30.0
Untreated check	...	...	5.22 ab	30.9
E 4242 10G	4.5 oz	furrow	5.33 ab	31.3
Fortress 10G	4.2 oz	7-in. band	5.33 ab	30.9
E 4242 10G	6.7 oz	furrow	5.50 ab	31.7
TF-3755	3.5 oz******	seed treatment	5.50 ab	30.8
E 4242 10G	9.0 oz	7-in. band	5.50 ab	32.9
XRD-522 .9EC	0.019 lb a.i.***	PPI*******	8.00 a	45.1

*Rate expressed as ounces of product per 1,000 feet of row.
**Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.05).
***Rate expressed as pounds of active ingredient per acre.
****Pre-emergence (PRE) treatments were broadcast on the soil surface 3 days after planting.
*****Liquids were applied in a 10-inch band in front of the presswheels at planting.
******Rate expressed as ounces of product per 100 pounds of seed.
*******Preplant incorporated (PPI) treatments were broadcast and disked into the upper 2 inches of the soil prior to planting.

The results of the evaluation of rescue treatments for BCW control are presented in Table 2. Dow's XRD-522 0.9EC and FMC's Pounce 3.2EC significantly reduced the level of cutting activity when compared to the amount of cutting in the untreated check. The lack of performance by Mobay's Baythroid 2EC and DuPont's Asana 1.9EC may be an indication that we exceeded the lowest effective rate for control with these two products.

Table 2. Evaluation of Rescue Insecticide Treatments for Control of Black Cutworms, Spring Barrier Study, University of Illinois Pomology Farm, Urbana, Champaign County, Illinois, 1988

Product	Rate*	Method of application	Mean number plants cut per barrier**	Mean percentage plants cut
XRD-522 0.9EC	0.015 lb a.i.	rescue	0.25 c	1.9
Pounce 3.2EC	0.1 lb a.i.	rescue	1.00 bc	5.9
XRD-522 0.9EC	0.01 lb a.i.	rescue	1.17 bc	7.3
Baythroid 2EC	0.0125 lb a.i.	rescue	2.60 a-c	17.5
Asana 1.9EC	0.0125 lb a.i.	rescue	3.33 ab	21.0
Untreated check	...	...	3.94 a	25.5

*Rate expressed as pounds of active ingredient per acre.
**Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, $p = 0.05$).

Conclusions. Given the low probability of cutworm infestations occurring in a cornfield (typically, less than 5 percent of the cornfields in Illinois require treatment for cutworms in any year), farmers continue to face questions when choosing a management strategy for cutworms. This year's data indicate that product choice, timing of application, and type of placement are also important considerations, especially during adverse environmental conditions. Not only must an individual weigh the uncertainty of a cutworm infestation, but it is obvious that in certain years the environment can negatively affect the performance of certain products. As a consequence, we continue to recommend that producers use a "wait and see" approach for management of BCW. If a grower has scouted a field and determined that a treatment is warranted, a rescue treatment is probably the best management selection.

Corn Rootworms

Methods. The effectiveness of soil insecticides for controlling corn rootworm larvae was evaluated in four trials located near Urbana, Bloomington, Monmouth, and DeKalb, Illinois, in 1988. All of the trials were established in fields that had been planted to corn around mid-June in 1987. However, because of relatively low to moderate corn rootworm pressure at three of the locations, only the results of the trial at DeKalb will be presented in this paper.

Corn was planted on May 5, 1988, at the Northern Illinois Agronomy Research Center near DeKalb, Illinois. Plots were established on 30-inch centers with a John Deere 7000 series four-row planter. Each treatment, except where otherwise noted, was applied to a single row approximately 100 feet long. The experimental design was a randomized complete block with four replications. Six untreated check rows were included in this test for comparative purposes.

Granular insecticides applied at planting were metered through Noble units mounted on each of the planter units. The planting-time granules were applied in furrow or in a 7-inch band ahead of the firming wheels on the planter. Spring tines mounted behind each planter unit were used to incorporate the insecticides into the soil at planting.

Again this year, we continued placement studies for split boot applications of Lorsban 15G. Two-thirds of the recommended rate of Lorsban 15G (2/3 rate = 5.35 oz per 1,000 ft of row) was metered evenly into a pair of fertilizer disk openers located in front of and on either side of the seed furrow disk opener. The granules were placed as close as possible to the same depth underground as the seeds were planted. The remaining one-third of the recommended rate of Lorsban 15G (1/3 rate = 2.65 oz per 1,000 ft of row) was applied directly into the seed furrow. The result of this application technique was three discrete insecticide placement sites beneath the soil surface at seed depth. In order to balance the effect of the fertilizer disk openers on the planter as it moved through the soil, split boot applications of Lorsban 15G were made to two adjacent rows within each replication.

Evaluations. Data for both root-damage rating and stand counts were recorded for all treatments in this test. Five root systems from each treatment in every replication were dug, washed, and rated for rootworm damage. We used the Iowa State University root-rating scale described as follows:

(1) No damage, or only a few minor feeding scars.
(2) Feeding scars evident, but no roots eaten off to within 1 1/2 inches of the base of the plant.
(3) Several roots eaten off to within 1 1/2 inches of the base of the plant, but never the equivalent of an entire node of roots destroyed.
(4) One node of roots completely destroyed.
(5) Two nodes of roots completely destroyed.
(6) Three or more nodes of roots destroyed.

Stand counts were determined by recording the number of plants per 1/1,000 of an acre (17.4 ft) in each single-row plot.

Results and Discussion. The results of the corn rootworm soil insecticide evaluation at DeKalb, Illinois, are presented in Table 3. With the adverse weather conditions that prevailed during this year's growing season, one might have expected to see some insecticide performance problems associated with corn rootworm control. However, this was generally not the case in this test. Average root ratings for all of the soil insecticide treatments in this test were significantly lower than the average root ratings in the untreated check plots. There were several treatments with mean root ratings between 3.00 and 3.55, but this level of damage is considered to be acceptable by some entomologists.

It is interesting to note that several products (ICI's E 4242 10G and Force 1.5G, Cyanamid's Counter 15G, AC 301468 15PG, and AC 513484 20PG) had numerically lower root-damage ratings when placed in furrow than when placed in a 7-inch band, even though these differences were not statistically significant. We have observed this trend for ICI's E 4242 in previous trials. However, this year's results might represent the other products' response to environmental conditions (more suitable moisture in furrow, less volatilization, etc.).

The results of the stand count comparisons indicate that plots treated with Cyanamid's AC 513484 20PG applied in furrow had significantly fewer plants per 1/1,000 acre than in plots treated with all other products and in the untreated checks. We also observed this trend for AC 513484 20PG applied in furrow in our other corn rootworm trials this year.

Conclusions. Despite adverse weather conditions, the performance of registered and experimental products in this test ranged from excellent to fair. We believe

Table 3. Corn Rootworm Soil Insecticide Evaluation, DeKalb, DeKalb County, Illinois, 1988

Product	Rate*	Method of application	Mean root rating**,***	Mean stand count***,****
E 4242 10G	9.0 oz	furrow	2.05 h	25.8 a
Fortress 10G	4.2 oz	7-in. band	2.20 gh	25.3 ab
Counter 15G	8.0 oz	furrow	2.30 f-h	24.0 ab
Fortress 10G	3.6 oz	7-in. band	2.35 e-h	25.8 a
Counter 15G	8.0 oz	7-in. band	2.40 d-h	27.3 a
E 4242 10G	9.0 oz	7-in. band	2.45 d-h	24.8 ab
AC 301468 15PG	8.0 oz	furrow	2.55 c-h	25.8 a
AC 301468 15PG	6.0 oz	furrow	2.55 c-h	26.3 a
AC 513484 20PG	6.0 oz	furrow	2.55 c-h	18.8 c
UAP 307 20G	8.0 oz	7-in. band	2.55 c-h	24.8 ab
UBI-B 8451 15G	4.0 oz	furrow	2.60 c-h	26.0 a
UBI-B 8451 15G	4.0 oz	7-in. band	2.60 c-h	25.3 ab
AC 301468 15PG	8.0 oz	7-in. band	2.65 c-h	26.8 a
Furadan 15G	8.0 oz	7-in. band	2.65 c-h	25.5 ab
UAP 101 20G	7.5 oz	7-in. band	2.65 c-h	24.8 ab
UBI-B 8451 15G	8.0 oz	7-in. band	2.65 c-h	25.5 ab
Fortress 10G	2.4 oz	7-in. band	2.70 c-h	26.0 a
AC 301468 15PG	6.0 oz	7-in. band	2.75 c-h	26.3 a
Brace 10G	6.0 oz	7-in. band	2.80 b-h	24.5 ab
Dyfonate 20G	6.0 oz	7-in. band	2.85 b-g	24.8 ab
Lorsban 15G	8.0 oz	7-in. band	2.85 b-g	25.5 ab
Lorsban 15G	8.0 oz	split boot #1*****	2.90 b-f	24.8 ab
UAP 101 20G	4.5 oz	7-in. band	2.90 b-f	24.8 ab
AC 513484 20PG	4.5 oz	furrow	2.95 b-f	23.8 ab
Dyfonate 20GM	6.0 oz	7-in. band	2.95 b-f	24.3 ab
Force 1.5G	10.0 oz	7-in. band	2.95 b-f	25.0 ab
Force 1.5G	8.0 oz	furrow	2.95 b-f	24.8 ab
Aastar 15G	8.0 oz	7-in. band	3.00 b-e	24.0 ab
Force 1.5G	10.0 oz	furrow	3.00 b-e	22.0 b
AC 513484 20PG	6.0 oz	7-in. band	3.05 b-e	24.3 ab
Lorsban 15G	8.0 oz	furrow	3.15 b-d	25.3 ab
Thimet 20G	6.0 oz	7-in. band	3.15 b-d	25.0 ab
Lorsban 15G	8.0 oz	split boot #2*****	3.25 bc	26.0 a
Broot 15GX	8.0 oz	7-in. band	3.30 bc	25.5 ab
Force 1.5G	8.0 oz	7-in. band	3.30 bc	26.5 a
UAP 307 20G	4.0 oz	7-in. band	3.30 bc	27.5 a
AC 513484 20PG	4.5 oz	7-in. band	3.55 b	25.8 a
Untreated check	...	...	5.30 a	25.9 a

*Rate expressed as ounces of product per 1,000 feet of row.
**Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6). Mean is based on 20 observations (4 replications x 5 samples per replication).
***Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.05).
****Stand counts are reported as the mean number of plants per 1/1,000 of an acre. All plots were seeded at 26,100 plants per acre.
*****Split boot applications made to two adjacent rows. See text for explanation.

this occurred largely because these products were applied at the proper rate and because they were placed appropriately for the best results. Unlike the results we observed in our BCW test, the registered and experimental soil insecticides in this test provided acceptable root protection even during an extraordinary growing season. It should be noted that black cutworms differ in susceptibility to insecticides and behave quite differently in the environment than corn rootworm larvae do.

First-Generation European Corn Borer

Methods. Field trials were established at the University of Illinois Pomology Farm in Urbana, Illinois, in order to compare the effectiveness of registered and experimental insecticides as rescue treatments for control of first-generation European corn borer (ECB) larvae. Corn plants were artificially inoculated with corn borers in order to generate comparisons among treatments. Plots consisted of four rows of corn 50 feet long. The experimental design was a randomized complete block with four replications.

On June 23, 1988, ten consecutive plants in each of the two middle rows of a four-row plot were infested with first instar ECB larvae (20 plants infested per four-row plot). An average of 50 to 60 first instar ECB larvae were mixed with corn grits and were discharged into the whorls with a hand-held "bazooka" applicator.

On July 1, 1988, about 8 days after the artificial infestation, insecticide treatments (granules and liquids) were applied with a modified John Deere 6000 high-clearance vehicle (HCV). Liquids were banded over the row with 8002E (Spraying Systems) even-flat fan nozzles mounted in brackets on the rear of the HCV. The height of the nozzles above the whorls was about 12 inches. Liquids were delivered with a compressed-air system calibrated to deliver 21.6 gpa at 40 psi and a ground speed of 3 mph. Granular insecticides were metered through Noble units mounted in brackets on the rear of the HCV. The Noble units were driven with electric motors and the granules were applied over the whorls in a 7-inch band. The banders were similar to those used on conventional planters to apply insecticide granules.

We recorded an average of 7.8 borers per plant from a 40-plant sample taken before insecticide applications were made. All but one of the plants sampled (98 percent) had first- and second-generation borers present in the whorl before the rescue applications were made.

Evaluations. On August 5, 1988, all of the plants that were infested were retrieved from the plots. Each plant was cut at the base with a corn knife and removed from the field. The mean number of cavities per plant, the mean length per cavity, and the mean percentage of plants with cavities were determined for all plots.

Results and Discussion. The results of the evaluation of registered and experimental rescue treatments for first-generation ECB control are presented in Table 4. Overall, granules were significantly more effective at reducing the level of damage when compared to the levels of damage in plots treated with liquid insecticides and in the untreated checks. This result was not unexpected because applied granules concentrate in the whorls of corn plants where young ECB larvae are actively feeding. In addition, our insecticide applications were timed to precede the development of the ECB population (typically, third and fourth instars begin to migrate from the whorl) and their subsequent movement from the whorl to other plant regions.

Table 4. Evaluation of Rescue Treatments for Control of First-Generation European Corn Borer, University of Illinois Pomology Farm, Urbana, Champaign County, Illinois, 1988

Product	Rate*	Mean number of cavities per plant**	Mean length (cm) per cavity	Mean percentage plants infested
Dyfonate 20GM	6.0 oz	0.01 d	1.00	1.3
Force 1.5G	8.0 oz	0.01 d	0.38	1.3
Lorsban 15G	8.0 oz	0.03 d	0.69	2.5
Furadan 15G	8.0 oz	0.06 d	2.00	6.3
E 4242 10G	6.7 oz	0.06 d	1.54	6.3
E 4242 10G	9.0 oz	0.08 d	2.00	7.5
E 4242 10G	4.5 oz	0.09 d	2.33	8.8
Capture 2EC	0.03 lb a.i.	0.36 c	3.46	32.5
XRD-522 0.9EC	0.019 lb a.i.	0.54 cb	3.14	41.3
Asana 1.9EC	0.025 lb a.i.	0.74 ab	2.80	53.8
Lorsban 4E	1.0 lb a.i.	0.75 ab	2.87	45.0
Asana 0.66EC	0.025 lb a.i.	0.91 a	3.17	56.3
XRD-522 0.9EC	0.015 lb a.i.	0.91 a	2.79	58.8
Untreated check	...	1.05 a	3.33	65.6

*Rates of liquids are expressed as pounds of active ingredient per acre; rates of granules are expressed as ounces of product per 1,000 feet of row.
**Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.10).

The lack of statistical differences among granular insecticide treatments may in part be explained by the optimum timing of the insecticide applications and by the fact that we used an HCV to make these applications. More typically, producers hire aerial applicators to make first-generation ECB rescue applications if they are warranted.

FMC's Capture 2EC and the high rate of Dow's XRD-522 0.9EC were the most effective liquid rescue treatments when compared to other liquid treatments and to the untreated check. In this test, DuPont's two formulations of Asana and the low rate of Dow's XRD-522 and Dow's Lorsban 4E were ineffective at reducing ECB damage. In general, liquids are less effective than granules for controlling first-generation ECB populations because they do not penetrate into the whorl as well as granules do.

Conclusions. Clearly, scouting cornfields is a necessary component of first-generation ECB management. If a rescue treatment for first-generation ECB is warranted, a well-timed aerial insecticide application is necessary to produce acceptable control. In our "worst case" trials (50 to 60 borers per plant), we were able to produce very effective control with appropriate timing of application. Liquids provide less effective control for first-generation ECB than granules do, even when applications are ideally timed. If you want to manage first-generation ECB damage in corn, you must scout your fields to ensure that a well-timed rescue application will be money well spent.

Management of Common Rust on Sweet Corn through the Use of Partial Resistance and Fungicides

J. Pataky and J. Headrick

Severe epidemics of common leaf rust *(Puccinia sorghi)* have occurred in the past 10 years on late-season sweet corn in northern Illinois, Wisconsin, and Minnesota when weather conditions were favorable. Rust was especially severe on popular shrunken-2 fresh market hybrids and sugary-1 processing hybrids that were rust-susceptible. Yield reductions of nearly 60 percent were observed on the most susceptible hybrids (Groth et al. 1983).

Recent research has provided much information that can improve disease management decisions for common rust on sweet corn. Relationships between sweet corn yield reductions and rust severity were quantified. Hybrids were grouped into resistance categories that were related to potential yield reductions due to rust. Environmental factors affecting rust development were identified. Relationships between rust incidence and severity were examined, and epidemic development of rust on partially resistant and susceptible hybrids was modeled in order to develop a fungicide action threshold. An adult plant rust-resistance reaction was identified. Fungicide trials are being done to test hypotheses concerning the need for fungicide applications at adult plant growth stages when rust-resistant reactions are evident.

YIELD LOSS AND RUST SEVERITY

Models were developed from experiments designed to estimate yield losses due to common rust (Pataky 1987). Variation in sweet corn yield was best explained by regression models in which the independent variable was rust severity assessed 1 week before harvest. Rust severity was measured with a Peterson scale (Figure 1) as the percentage of the total leaf area infected by *P. sorghi*. General linear models derived from three hybrids grown in three different environments estimated that sweet corn yield (measured as ear weight and as number of marketable ears) was reduced 0.6 percent for each 1 percent rust severity (Figures 2 and 3). Thus, disease control tactics that reduce rust severity can be evaluated in terms of yield based on the 0.6 percent to 1 percent relationship between yield loss and disease.

RUST RESISTANCE IN COMMERCIAL HYBRIDS

Over 400 commercial sweet corn hybrids have been evaluated for rust reactions since 1984 (Pataky et al. 1987a, Pataky et al. 1987b, Pataky et al. 1988). Based on population distributions and statistics, hybrids were grouped into four resistance categories: resistant (R), moderately resistant (MR), moderately susceptible (MS), and susceptible (S). Hybrids were identified as "standards" in each category in order to compare trials (Figure 4). For example, from 1984 through 1987, Miracle (R), Honey n Frost (MR), Summer Sweet 7200 (MS), and Florida Staysweet (S) were the four "standards" for rust-resistance categories (Figure 4). In these trials, a few hybrids possessed Rp-resistance which did not allow any rust to develop. Other resistant hybrids allowed low levels of rust development. Since 1984, rust severity has ranged from 0 to 20 percent on R hybrids, from 15 to 30 percent on MR hybrids, from 25 to 40 percent on MS hybrids, and from 30 to 80 percent on S hybrids. Corresponding yield reductions for these four categories of hybrids were estimated from yield loss models and ranged from 0 to 12 percent for R hybrids, from 9 to 18 percent for MR hybrids, from 15 to 24 percent for MS hybrids, and from 18 to 48 percent for S hybrids. Thus, under rust-conducive environments in which epidemics occur, yield reductions due to rust would be relatively small for R hybrids and quite substantial for MS and S hybrids.

ENVIRONMENT AND RUST EPIDEMICS

Temperature and moisture conditions that affect *P. sorghi* population development were studied in growth chamber experiments in an effort to develop a weather-based forecast for fungicidal control of rust (Headrick and Pataky 1986). Rust spore germination was optimal when at least 6 hours of leaf (or whorl) moisture occurred. At 24^{o} and 32^{o}C day temperatures, rust developed rapidly when night temperature was 16^{o} or 24^{o}C. At 8^{o}C nights, *P. sorghi* latent periods were extended by about 2 days. At 32^{o}C nights, very few pustules formed as most infections became necrotic without sporulating. Thus, at very cool or hot night temperatures or under very dry conditions, rust development was slowed considerably. However, under temperature and moisture conditions that commonly occur late in the growing season in sweet corn producing areas, the rate of rust development was sufficient to prohibit the use of a weather-based forecast to predict timing of fungicide applications.

THRESHOLDS FOR RUST CONTROL

Results from experiments on relationships between rust incidence and severity (Dillard and Seem 1987, Pataky and Headrick 1988) and on modeling of rust epidemic development (Headrick and Pataky 1988) were used to estimate action thresholds for fungicidal control of rust. Relationships between rust incidence and severity were similar for partially resistant and susceptible hybrids when incidence was below 100 percent (Figure 5). From 20 to 60 percent incidence, severity was about 1 percent. Rates of rust increase and spread were two to eight times higher on a susceptible hybrid than on a partially resistant hybrid. Based on these relationships, an action threshold of six pustules per leaf was proposed, which corresponded to about 1 percent severity. This threshold is particularly important for susceptible and moderately susceptible hybrids that are at the three- to five-leaf stage of growth late in the season when environments are rust-conducive. The threshold decreases in importance as plant growth stage and levels of partial resistance increase.

ADULT-PLANT RUST REACTIONS

Sweet corn hybrids varying in levels of partial resistance to *P. sorghi* were inoculated simultaneously in the field at eight stages of growth ranging from the five-leaf to late silk stages (Headrick and Pataky 1987). Rust severity was lowest on plants that were inoculated at the late silk stage, and highest on plants inoculated at the five-leaf stage (Figure 6). As plant age increased, rust severity decreased on all hybrids. The "adult-plant" resistant reaction was most apparent after the onset of reproductive growth (tasseling) of the host.

Apparently, the adult-plant reaction is a universal property of all sweet corn genotypes and is a function of plant age, whereas partial resistance is a genotype-specific trait and functions at all host growth stages. Both types of resistance reduced the number of pustules per leaf and will reduce the need for fungicidal control.

TIMING OF FUNGICIDES FOR RUST CONTROL

Experiments are currently being done to evaluate the timing of fungicide applications for control of rust on hybrids with various levels of partial resistance (Pataky 1987). Preliminary results indicated that three weekly applications from the four-leaf stage (1 percent action threshold) until the eight-leaf stage were as effective as four or five sprays that continued through the ten-leaf or early tassel growth stages, respectively (Figure 7). For hybrids in all resistance categories (R, MR, MS, S), there were no differences in rust severity among three, four, and five fungicide applications, apparently due to the adult-plant resistant reactions. Rust severity 1 week before harvest on susceptible and moderately susceptible hybrids with three fungicide applications was equal to that of a partially resistant hybrid with 0, 1, or 2 applications. Severity on the susceptible hybrid with two applications (four-leaf and six-leaf stages) was equal to the intermediate (MS and MR) hybrids with no control. Further experimentation to test these hypotheses is being done with mancozeb (Dithane M-45) and propiconazole (Tilt 3.6E).

SUMMARY

The value of rust control can be measured in terms of yield, based on a 0.6 to 1 percent relationship between yield loss and rust severity. For example, a control practice that prevents a 10 percent increase in rust severity also prevents a 6 percent reduction in yield. Rust management through the use of resistance and fungicidal control can be evaluated from this relationship.

The first step in rust management is to identify levels of partial resistance or susceptibility of hybrids. Hybrids that are categorized resistant or moderately resistant are less likely to sustain substantial damage under severe rust epidemics. These hybrids require fewer (if any) fungicide applications to achieve adequate control. Moderately susceptible and susceptible hybrids generally require fungicide protection in order to prevent some yield reduction under late-season rust-conducive environments. Current research indicates that a six-pustule per leaf (1 percent severity) action threshold should be adequate in preventing rust epidemic development. This threshold is appropriate except under extremely dry conditions or particularly cool (below $8^{o}C$) or hot (above $30^{o}C$) temperatures. Weekly fungicide applications from the action threshold until the eight- to nine-leaf stage have effectively controlled rust in preliminary studies. Additional fungicide applications beyond the eight- to nine-leaf stage have not been necessary, probably because the adult-plant rust reactions have rendered all sweet corn hybrids more resistant to *P. sorghi* at later growth stages.

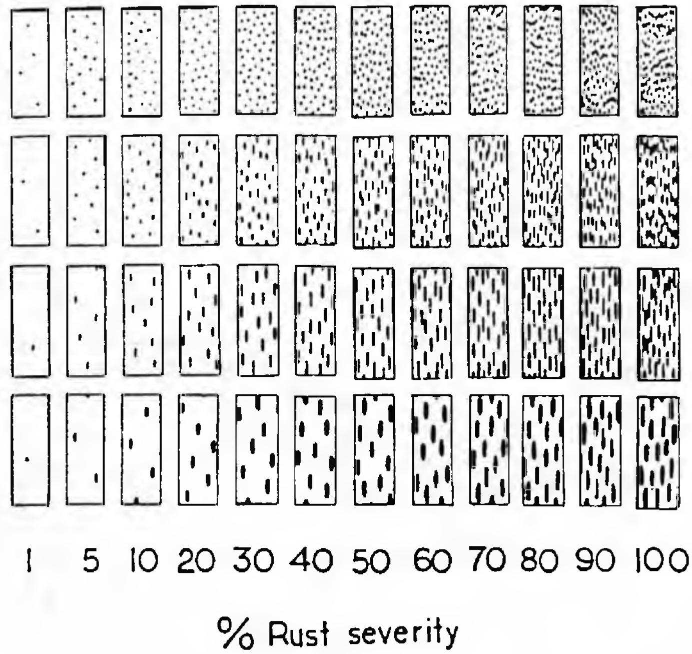

Figure 1. Standard area diagrams for estimating rust severity on leaves of sweet corn. Black areas represent pustules. Top scales are used early in an epidemic when pustules are small. Lower scales are used when pustules are larger.

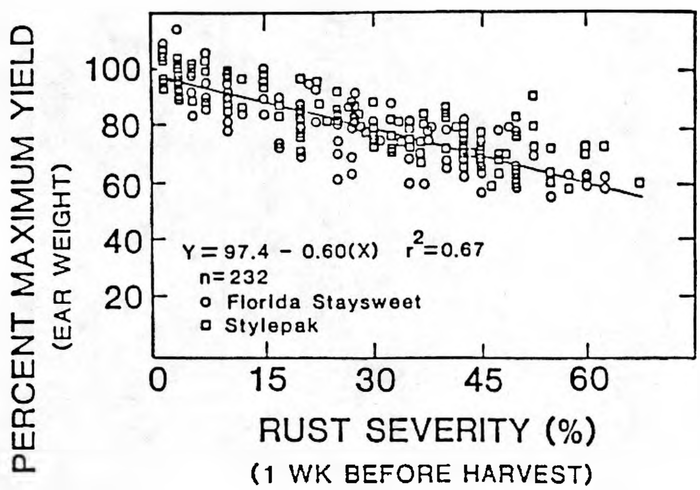

Figure 2. Regression of percent maximum sweet corn ear weight on rust severity 1 week before harvest for combined data of Florida Staysweet and Stylepak evaluated in 1984, 1985, and 1986 field trials. This relationship shows that for each 1 percent rust severity a week before harvest, total ear weight is reduced 0.6 percent.

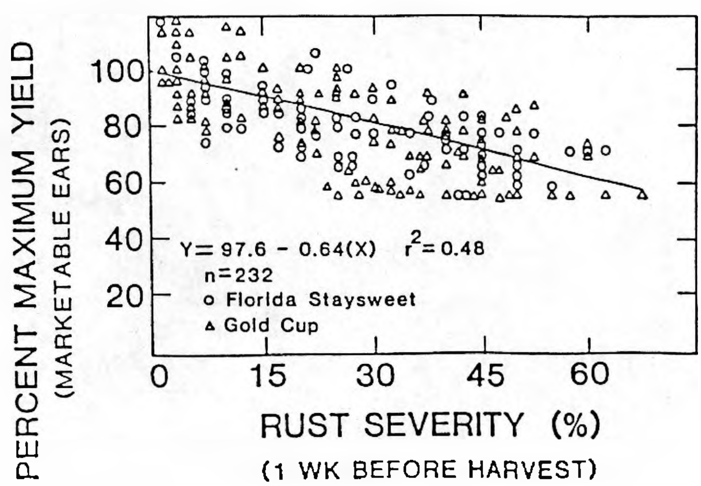

Figure 3. Regression of percent maximum number of marketable sweet corn ears on rust severity 1 week before harvest for combined data of Florida Staysweet and Gold Cup evaluated in field trials in 1984, 1985, and 1986. This relationship shows that for each 1 percent rust severity a week before harvest, the total number of marketable ears is reduced 0.65 percent.

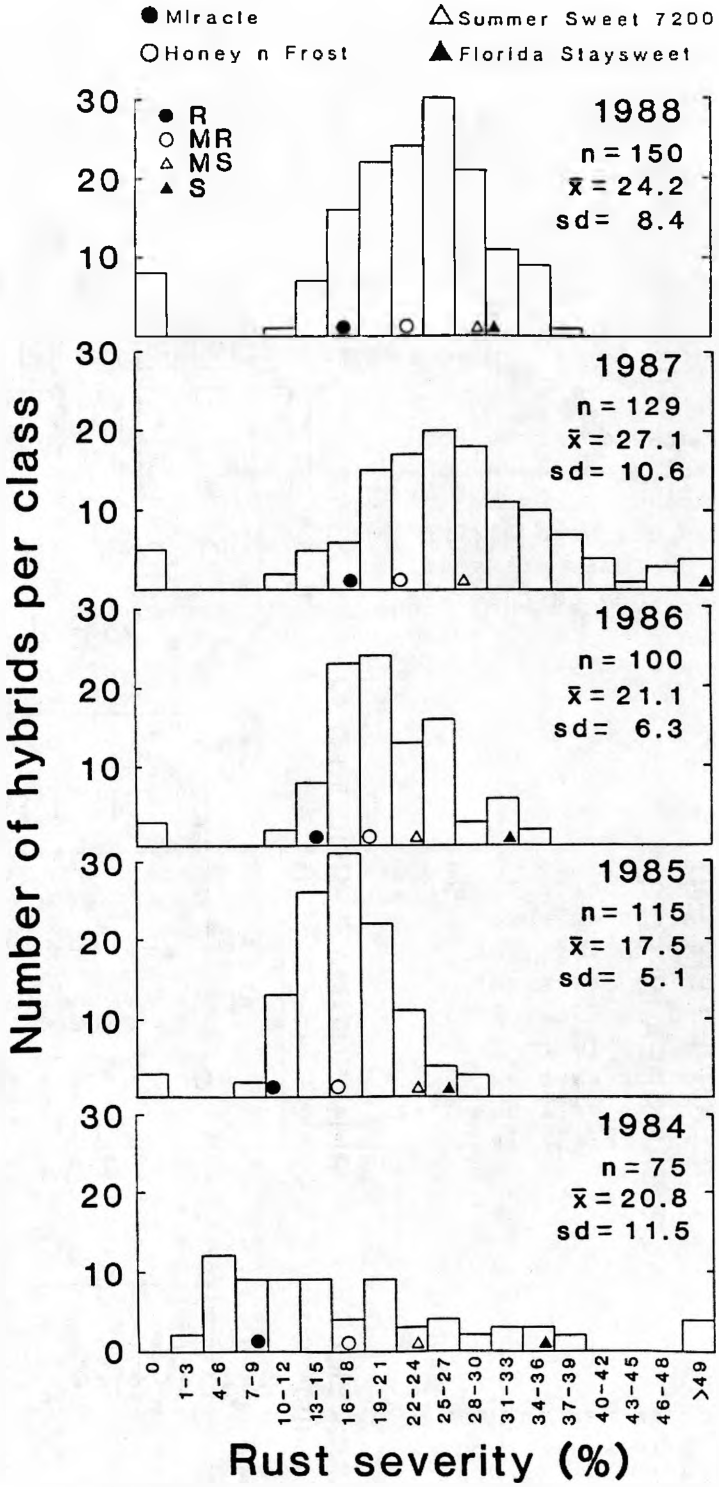

Figure 4. Distributions and sample statistics of sweet corn hybrids evaluated for rust reactions in disease nurseries from 1984 to 1987. Rust severity on standard hybrids--Miracle (R), Honey n Frost (MR), Summer Sweet 7200 (MS), and Florida Staysweet (S)--respectively, was less than -0.8, from -0.8 to 0, from 0 to 0.8, and greater than 0.8 standard deviations from the population mean in each year.

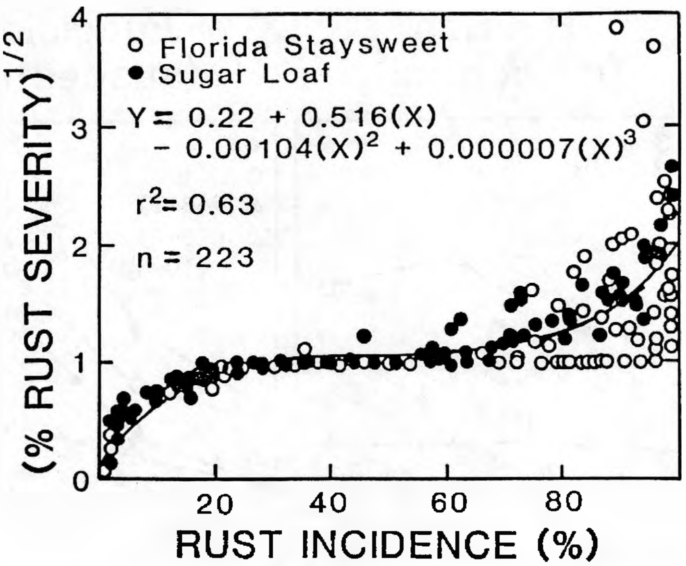

Figure 5. Rust severity (percent) [square root transformed] plotted on rust incidence for a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid grown in four experiments designed to study rust development. Severity is about 1 percent when incidence ranges from 20 to 60 percent. As incidence approaches 100 percent, severity begins to increase rapidly.

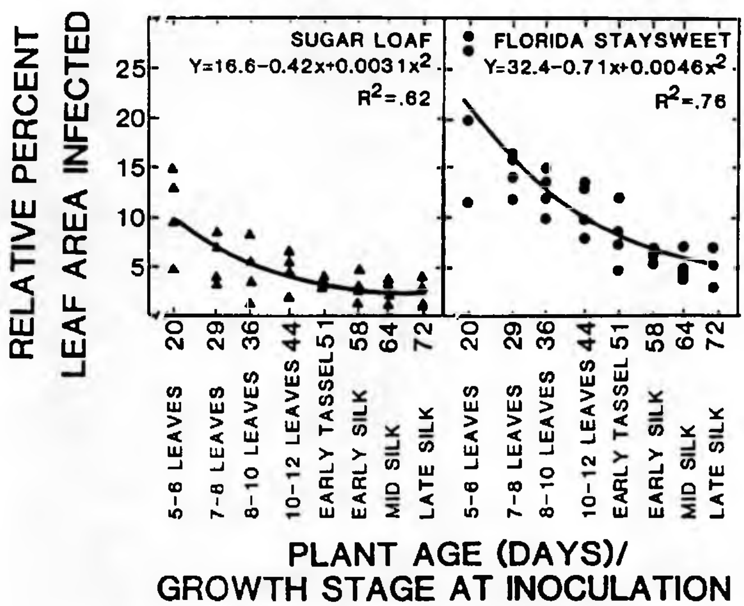

Figure 6. Regression of common rust severity (percent leaf area infected) on host plant age for a susceptible (Florida Staysweet) and a partially resistant (Sugar Loaf) sweet corn hybrid. The position of the two lines reflects the difference in partial resistance and susceptibility of Sugar Loaf and Florida Staysweet, respectively. The slope and curvature of the lines reflect the adult-plant rust-resistant reaction observed in all sweet corn genotypes. At 10 days after inoculation (before secondary spread occurs), rust severity is greater on younger plants than on older plants.

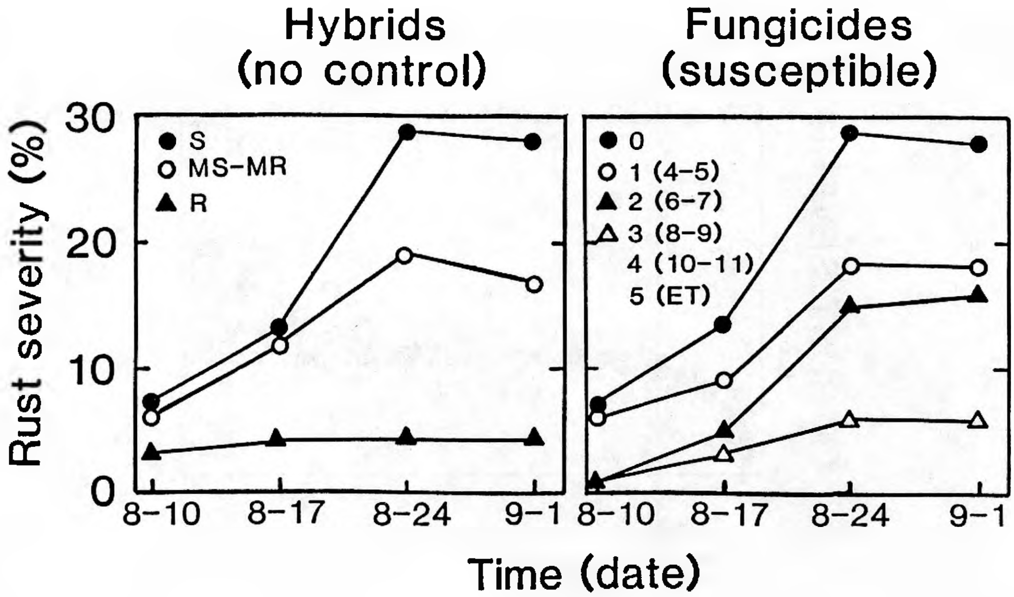

Figure 7. Rust development in time for hybrids partially resistant (R), intermediate (MR, MS), and susceptible (S) to common rust; and rust development on a susceptible hybrid to which 0 to 5 weekly fungicide applications were made beginning at the four- to five-leaf stage. No differences were observed between 3, 4, and 5 application treatments.

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On-Board Impregnation and Other Developments in Application Technology

M. Broder

Application of fertilizer in the United States has advanced considerably during the past 40 years. Development of granular fertilizer permitted broadcasting, which saves time and increases the width of area covered in a single pass. Liquid fertilizers, suited for several kinds of metering systems, fostered the development of nozzles, flow dividers, and special pumps. Suspension fertilizers also created a need for new equipment. New and more reliable sensors and electrical and hydraulic controls promoted use of rate monitors and controllers.

CUSTOM APPLICATORS

Innovations to simplify the task of the operator are common on custom application equipment. Custom machines are equipped with electronic monitors and controls that automatically adjust fertilizer output to compensate for applicator speed changes. A diagram of an automatic rate controller on a high-flotation liquid applicator is shown in Figure 1. Custom equipment usually has a radar speed sensor, which has largely replaced mechanical speed sensors that give erroneous signals when wheels slip.

Automatic rate controllers are available for dry fertilizer spreaders. These controllers also monitor speed, but the rate is maintained by controlling hydraulic fluid flow to the motor that drives the fertilizer supply apron. Unlike the liquid controller which keeps nozzle pressure proportional to the square of applicator speed, the dry controller keeps apron speed directly proportional to applicator speed. An anhydrous ammonia rate controller is also available. It meters liquid anhydrous ammonia with a valve in the output line and has an evaporative heat exchanger that delivers liquid ammonia through the metering valve. The anhydrous ammonia applicator has no pump. The ammonia escapes under its own pressure from the supply tank.

As in automobiles, fuel efficiency has become a major selling point of liquid custom applicators. Applicator vehicles are being equipped with more efficient diesel engines and wider booms. Hinged booms can be used for either a 55- or 85-ft swath. With booms fully extended, a liquid applicator can cover 3 acres per minute when traveling at a speed of 18 miles per hour.

DRY FERTILIZER APPLICATION

The most novel innovations in custom applicator design have involved dry fertilizer applicators. The centrifugal (spinner) spreader, common since 1950, has long been considered the reason for poor fertilizer distribution. Several boomed spreaders now available are being promoted as the machines that will make spinner spreaders obsolete. One has augers; the others are pneumatic.

The auger system has been marketed on a regular truck chassis for several years in the Northwest. It is now being marketed on a high-flotation chassis by one of the largest manufacturers of high-flotation applicators. The latest version (Figure 2) has two lift augers that are gravity fed from the hopper and two 5-inch augers that supply each boom. Beneath each boom supply auger is an agitator and a metering screw that meters the fertilizer through holes spaced 6 inches apart. The metering screw is driven hydraulically from a pump driven from the vehicle drive shaft. This keeps the metering screw speed proportional to applicator speed.

A sketch of an early version of the most popular pneumatic dry fertilizer spreader is shown in Figure 3. The rate of application is controlled, as in conventional spinner spreaders, by controlling apron speed. Fertilizer is distributed to outlets by a vertical auger that conveys material from beneath the supply apron to a manifold. A wiper on the top of the vertical auger distributes fertilizer to 20 openings. Vertical tubes transfer fertilizer from the openings downward to lateral tubes that supply 20 nozzles. The 3-inch lateral tubes are fed air at high speed from two headers. A venturi is positioned in each lateral to create suction on material dropping from the distributor head. Nozzles consist of deflector shields positioned just below the outlets of the lateral tubes.

Five other pneumatic spreaders are being marketed in the United States. The potential demand for these machines is so great that companies have developed them in spite of depressed sales of application equipment. A major reason for the popularity of boomed spreaders is the demand for uniform application of impregnated blends. About half of the bulk-blend retailers offer weed and feed services using blends impregnated with liquid herbicides.

SUSPENSION FERTILIZER APPLICATION

The adoption of suspension fertilizers has led to the development of flow dividers for row and band application. Suspension fertilizers are popular for several reasons. Phosphate from several sources can be used in suspensions. Suspensions contain more plant food than do liquids, yet share their desirable handling characteristics. Before suspensions became popular, liquid fertilizers were row-applied by gravity feeding from a tank over each row or by pumping them through manifolds with ground-driven piston pumps. But because of crystals, suspensions could not be gravity fed and they often caused fouling of valves in piston pumps. The squeeze (hose) pump is a less expensive alternative to the piston pump. It moves suspension by pressing rollers against flexible hoses. There is very little pressure, no flow divider is required, and there are no valves. The squeeze pump, however, must be mounted beneath the supply tank for trouble-free operation, and it is not well suited for large applicators (20 or more outlets).

As the number of outlets on row equipment increased, so did the demand for a flow divider that could be used in a pressure system. The first suspension flow divider designed for large row applicators is shown in Figure 4. It has a vented pot into which liquid is distributed with a hollow cone nozzle. The pot is compartmentalized and each compartment drains into a single hose that supplies an application knife or dribble tube. Because the compartments drain more rapidly than they are filled, equal-length lines to each knife are not required. This is a major advantage for this and similar flow dividers.

Another suspension flow divider uses a system of multiple orifices to equalize the pressure drop through the manifold and to produce lower outputs than would be possible through a single orifice (Figure 5). Unlike the pot system, one or more outlets on this divider may be plugged to reduce the number of outlets without decreasing uniformity of distribution.

Figure 6 is a sketch of another suspension flow divider. This divider combines different inlet and outlet orifices to produce a range of application rates. The number of outlets on this divider can also be reduced by using plugs without altering distribution uniformity.

Another suspension flow divider also has radial compartments in a circular pot. Suspension is distributed to the compartments by a solid disc that spins around a vertical axis. Energy required to spin the disc comes from the momentum of a solid stream of suspension passing through a spiraled hole in the disc. A solid-stream nozzle mounted in the top of the pot directs suspension into the spiraled hole.

INNOVATIONS INSPIRED BY AGRONOMY

Some innovations in application involve the positioning of fertilizer in the soil and are the result of agronomic research. The shift by farmers to minimum or reduced tillage has precluded the conventional practice of mixing broadcast fertilizer into the soil during tillage. Researchers are improving the efficiency of fertilizers by injecting them below the soil surface or banding them on the soil surface in minimum tillage situations. These application methods are often referred to as precision placement methods.

Phosphorus and potassium, relatively immobile nutrients, can be relatively unavailable to plant roots when broadcast in minimum tillage systems. Nitrogen can become immobilized by microorganisms in the layer of organic matter that covers the surface in reduced tillage systems. Urea, which is replacing ammonium nitrate as a source of nitrogen, is more susceptible to loss by volatilization than its predecessor. For this reason, some agronomists recommend that urea be incorporated into the soil under many circumstances. One unique application method adopted by farmers in the U.S. wheat belt is dual application. Dual application is the simultaneous injection of nitrogen, usually anhydrous ammonia, and phosphate. Liquid phosphate, 10-34-0 grade ammonium polyphosphate solution, is most common; however, suspensions and dry sources of phosphate are used.

Strip or dribble application is accomplished several ways. Liquids are dribbled from low-pressure systems (squeeze pump and plot flow dividers) by spacing hose outlets along a boom or tool bar. In pressure systems, special nozzles that produce one or more narrow streams of liquid are used. Some custom applicators place a flexible hose over each broadcast nozzle to restrict the spray to a solid stream. One equipment manufacturer has designed kits for converting high-volume sprayers to strip applicators. These strip kits, as they are called, attach to the boom as nozzles do and split the flow from each outlet on the boom into two or three solid streams. With 60-inch nozzle spacing, either a 20- or 30-inch strip spacing is obtainable.

Fertilizer delivery systems on subsurface injection equipment are identical to those on surface banding equipment. Pneumatic systems are preferred for custom application of dry fertilizer. High-flotation applicators have a 35- or 40-ft tool bar attached to the rear of the vehicle frame. The centrifugal pump used for broadcast application is also used for injection. Unique to injection systems are the knives used. Spring tines or chisel blades are used to inject liquid and dry fertilizers beneath the soil surface. For liquids, a 1/4-inch delivery tube is often welded to the back side of the chisel. Suspensions are usually conveyed through a flexible hose attached to the back of the chisel with a metal bracket. Dry materials are conveyed through a 3/4-inch or larger pipe welded to the back of the chisel.

Dual application rigs have an anhydrous ammonia delivery system as well as one for dry or liquid fertilizer. The ammonia is usually metered under its own pressure with a variable orifice meter. The injection knife has the phosphate outlet directly behind and slightly above the ammonia outlet. When liquid phosphate is used, the ammonia and phosphate outlets often must be separated to prevent freezing of the phosphate by the expanding ammonia.

A unique tillage tool used for dual application is the V-blade chisel plow. Unlike knife systems, which usually have liquid phosphate capabilities, many V-blade systems use a pneumatic dry-phosphate system. Advantages of the V-plow are that it helps to preserve soil moisture and that fertilizer row spacings can be changed without changing plow spacing. In some experiments, planting and ammonia fertilization were achieved simultaneously with a V-plow. Results were inconsistent; germination was reduced in some plots but not in others.

A new machine injects a solid stream of liquid fertilizer at 2,000 pounds per square inch (psi) into the soil without a knife. A high-pressure piston pump delivers liquid to solid-stream nozzles mounted in shoes that slide along the soil surface or residue surface. This approach was used in the 1960s to inject anhydrous ammonia into soils not well suited for conventional knifing. The practice has been revived for injecting fertilizer under minimum tillage. It minimizes the disturbance of the soil surface and avoids the problems of trash accumulation on shanks of applicator knives.

Another unique injection system has been developed by a Midwestern university. This device, called the spoke injector, resembles a spoked wheel without a rim. The hub has a cavity in which liquid fertilizer is delivered under pressure. The internal design of the hub is such that liquid is forced out of the hub and through a spoke only when the spoke is aimed vertically downward. The outlet hole on each spoke is on the side of the spoke near the end to prevent clogging. Like the high-pressure injector, the spoke injector produces no slit that increases the erosion potential of a field. The knife rigs, on the other hand, create some potential for erosion when they are operated up and down hills.

Other interesting devices that have been patented but are not yet in common use include radar-controlled automatic boom levelers and radar applicator guidance systems. An on-board herbicide injection system can meter chemicals into the output line on an applicator. The most appealing aspects of this device are the conservation of chemical and elimination of chemical waste disposal. Without the chemical injection system, applicators must be flushed with water after spraying chemicals.

FUTURE TRENDS

Emphasis on accurate fertilizer application will aid development of more accurate metering systems, better monitors, and more sensitive sensors. Measurement of fertilizer output from automatic rate controllers has revealed that some controllers cannot respond to rapid changes in applicator speed. Faster-acting servomotors are being developed to eliminate these time lags in metering response. An organic-matter sensing device has been tested, which will be used to adjust application rates of triazine herbicides. These herbicides are organic-matter sensitive. This marks the beginning of a technology that some believe will eventually evolve to sensing of soil fertilizer nutrient content.

There is much interest among researchers in site-specific control of nutrient application rates. Preliminary tests have shown that comparable yields can be achieved with less fertilizer, using this approach.

A new applicator is available that automatically adjusts the rate of up to six different granular products--on-the-go. Special maps and soil tests are interpreted by an on-board computer that constantly tailors the blend to each area in the field.

The cost of automatic rate controllers--the heart of on-the-go rate adjustment--should decrease, and the reliability and simplicity of these devices should improve in the future. Emphasis on better fertilizer and herbicide application will speed the use of rate sensors and controllers to improve accuracy.

Application of fertilizer/herbicide mixtures, liquid and dry, is a service offered by most U.S. fertilizer dealers. Proper handling, recycling, or disposing of rinsate is one of the most serious problems facing dealer-applicators.

The common practice of batch-mixing herbicides and fertilizer will likely be abandoned because of the amount of equipment that must be rinsed--mix tank, nurse equipment, and applicator. Some dealers are already developing systems to limit the volume of rinsate produced.

Researchers are experimenting with machinery that can impregnate granular fertilizer during application, limiting pesticide exposure to the application vehicle. Although centrifugal spreaders do not lend themselves to this practice, some of the boomed dry spreaders have augers for lifting fertilizer that could serve as mixers for impregnation.

Another incentive for impregnation during application is to vary herbicide rates on-the-go. Chemicals could then be matched to soil type and weed pressure for specific areas, providing the same control for less cost.

Fertilizer application is now a far more precise operation than in the past. Much work remains to be done, however, in lowering the cost of application by improving delivery systems to the farm, increasing uniformity of application, and refining metering equipment. More efficient application systems and low-cost fertilizers that work with them are keys to success in tomorrow's fertilizer industry.

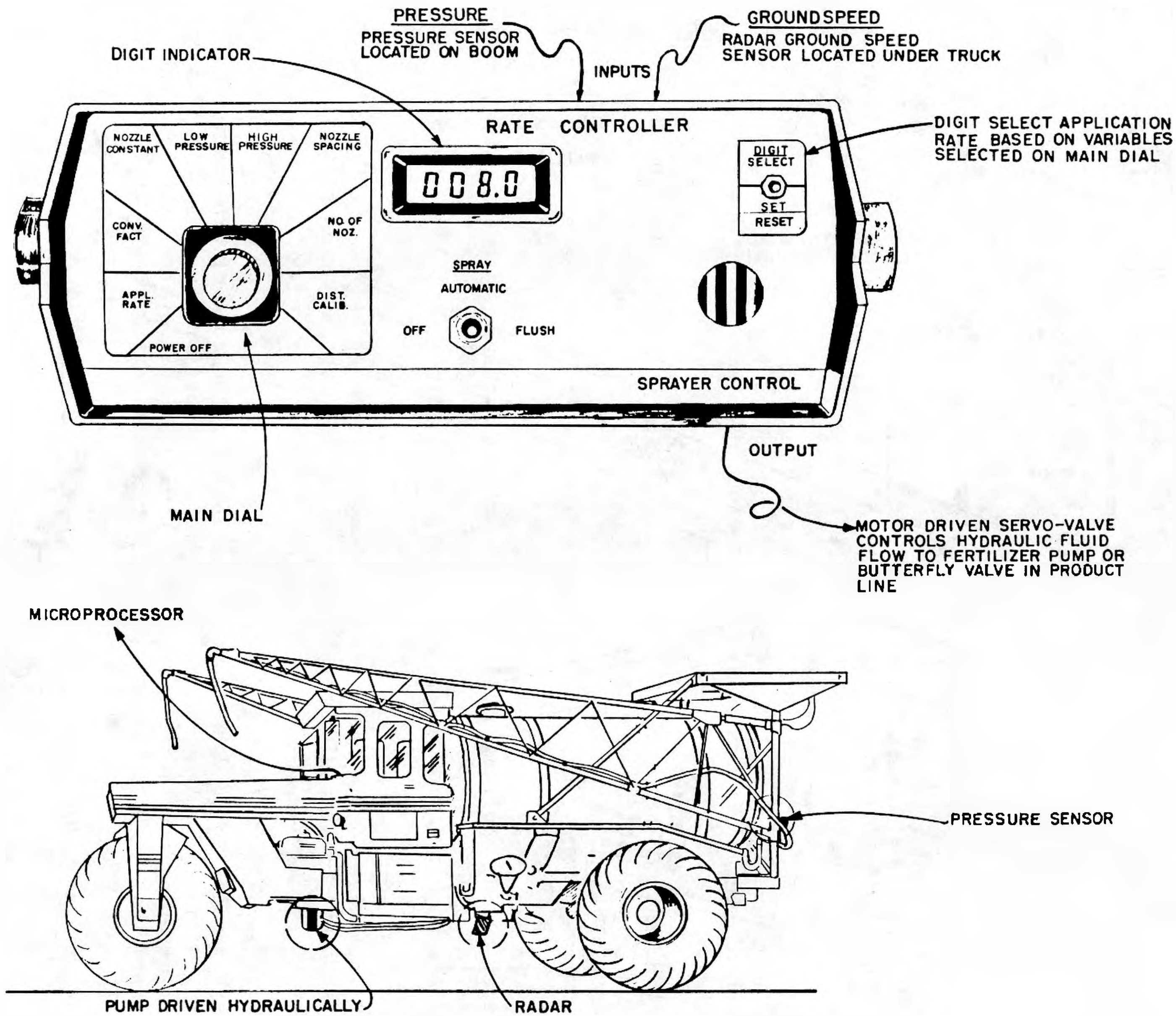

Figure 1. Electronic rate controller for liquid applicator.

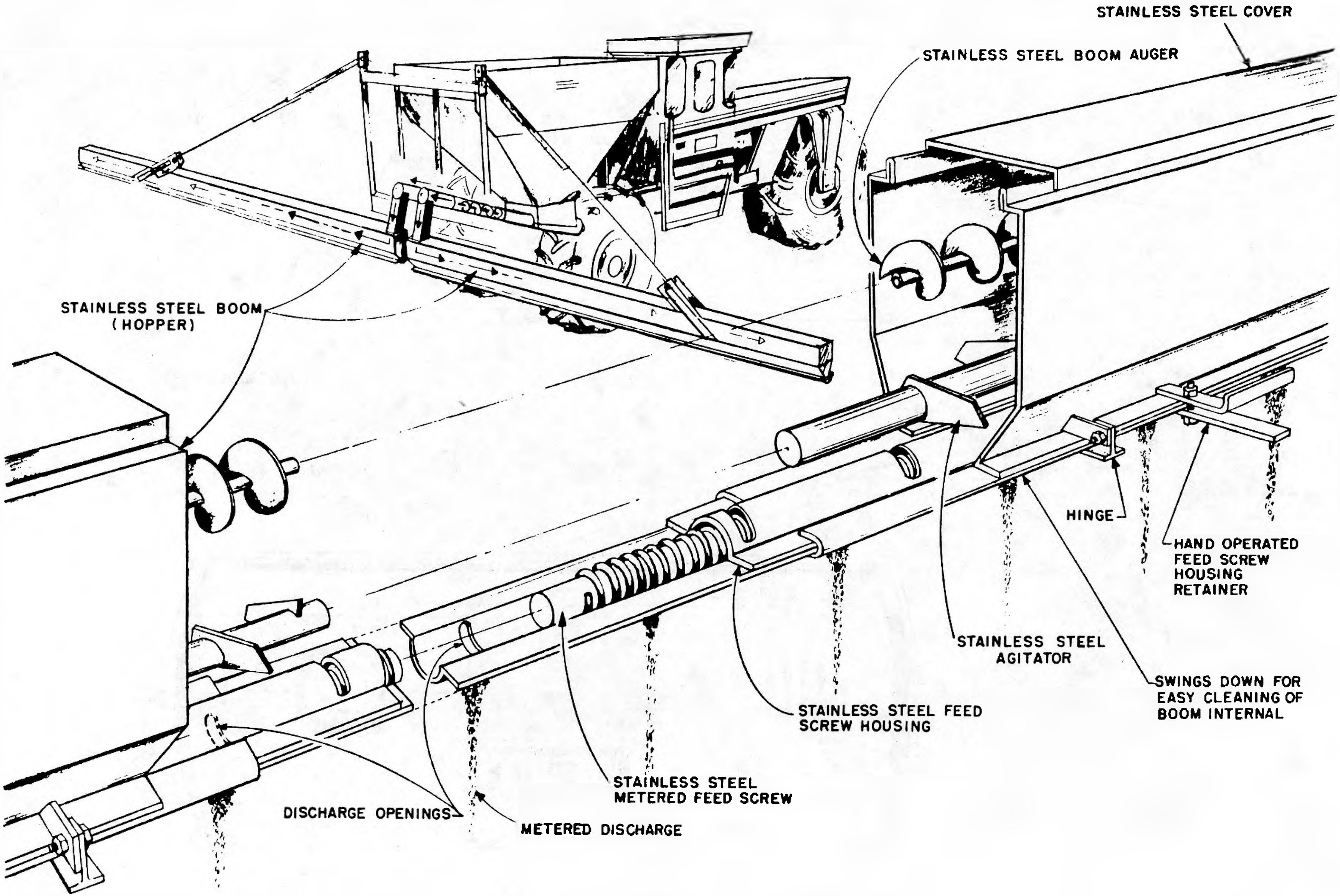

Figure 2. Ag-Chem/Barber auger spreader.

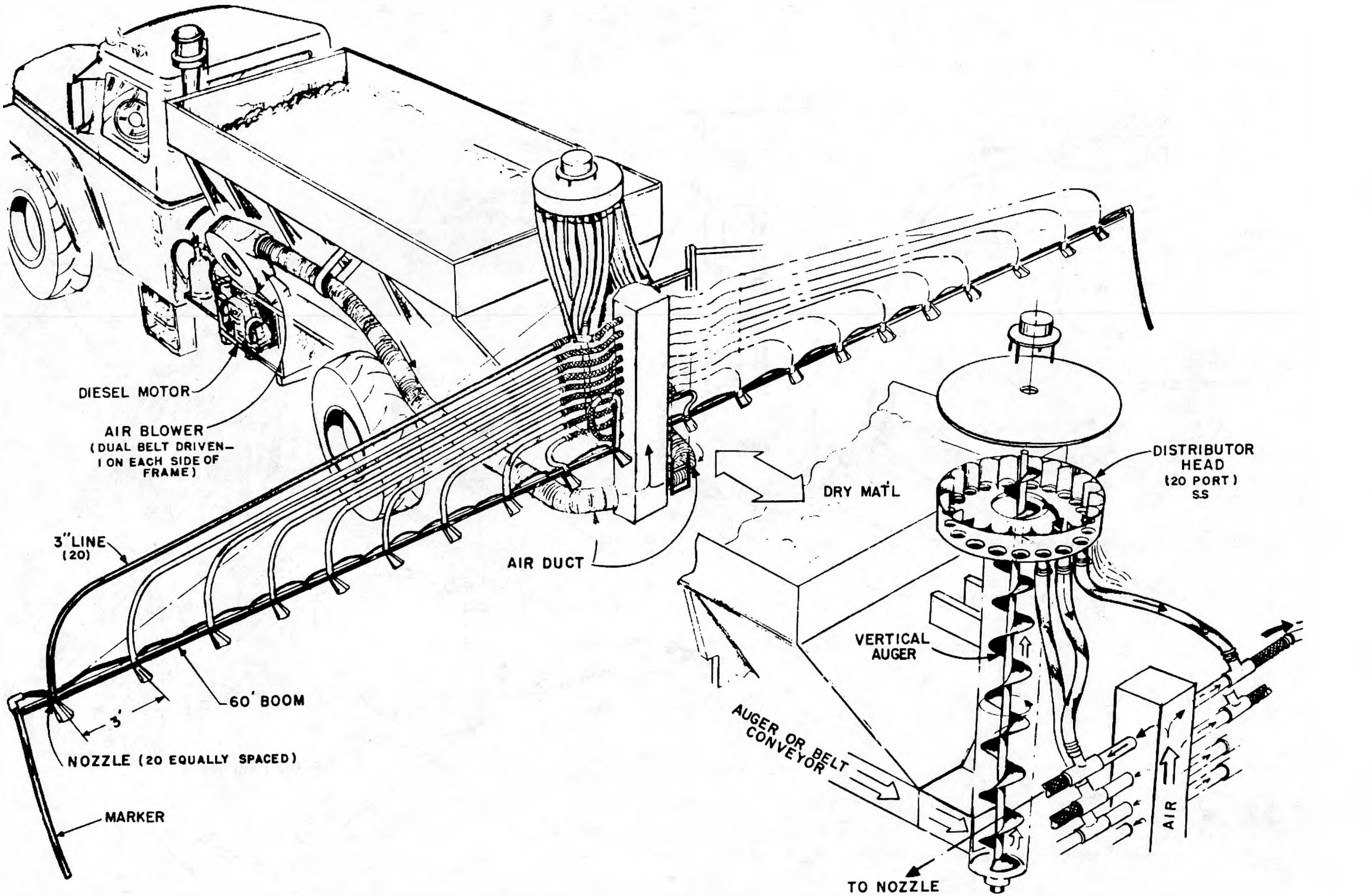

Figure 3. Lor-Al air-flow spreader.

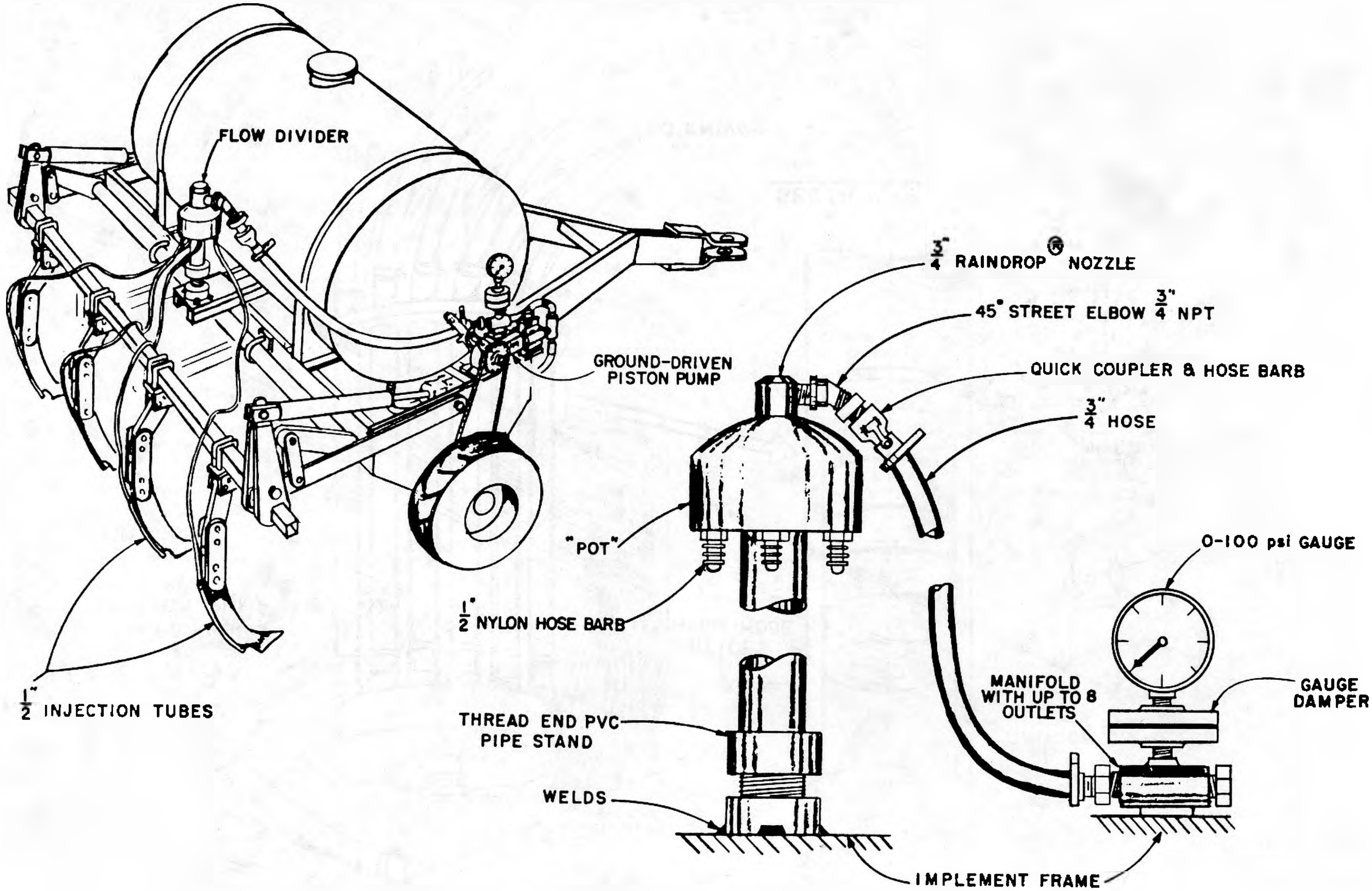

Figure 4. Flow divider for suspension injection.

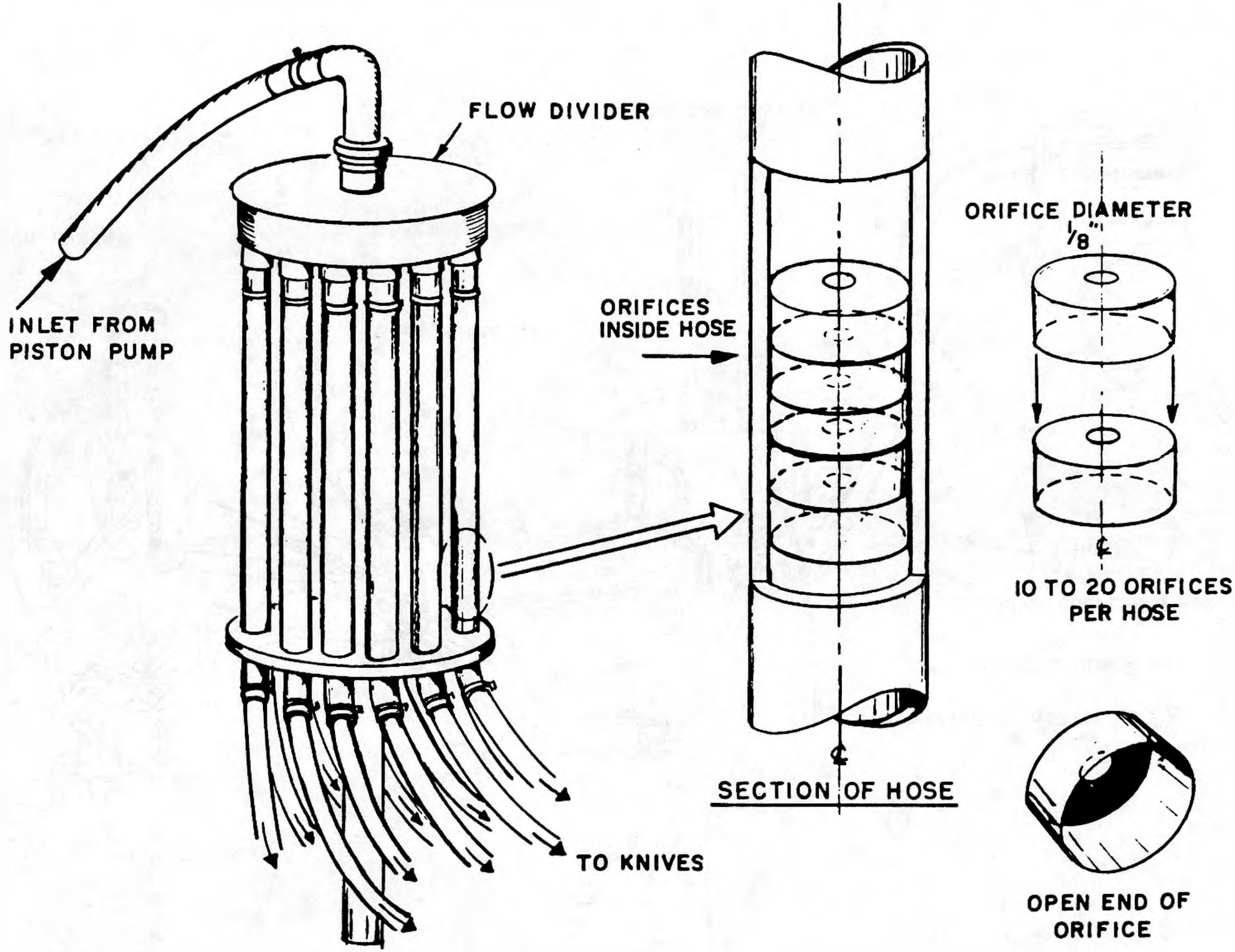

Figure 5. John Blue flow divider for row application of liquids.

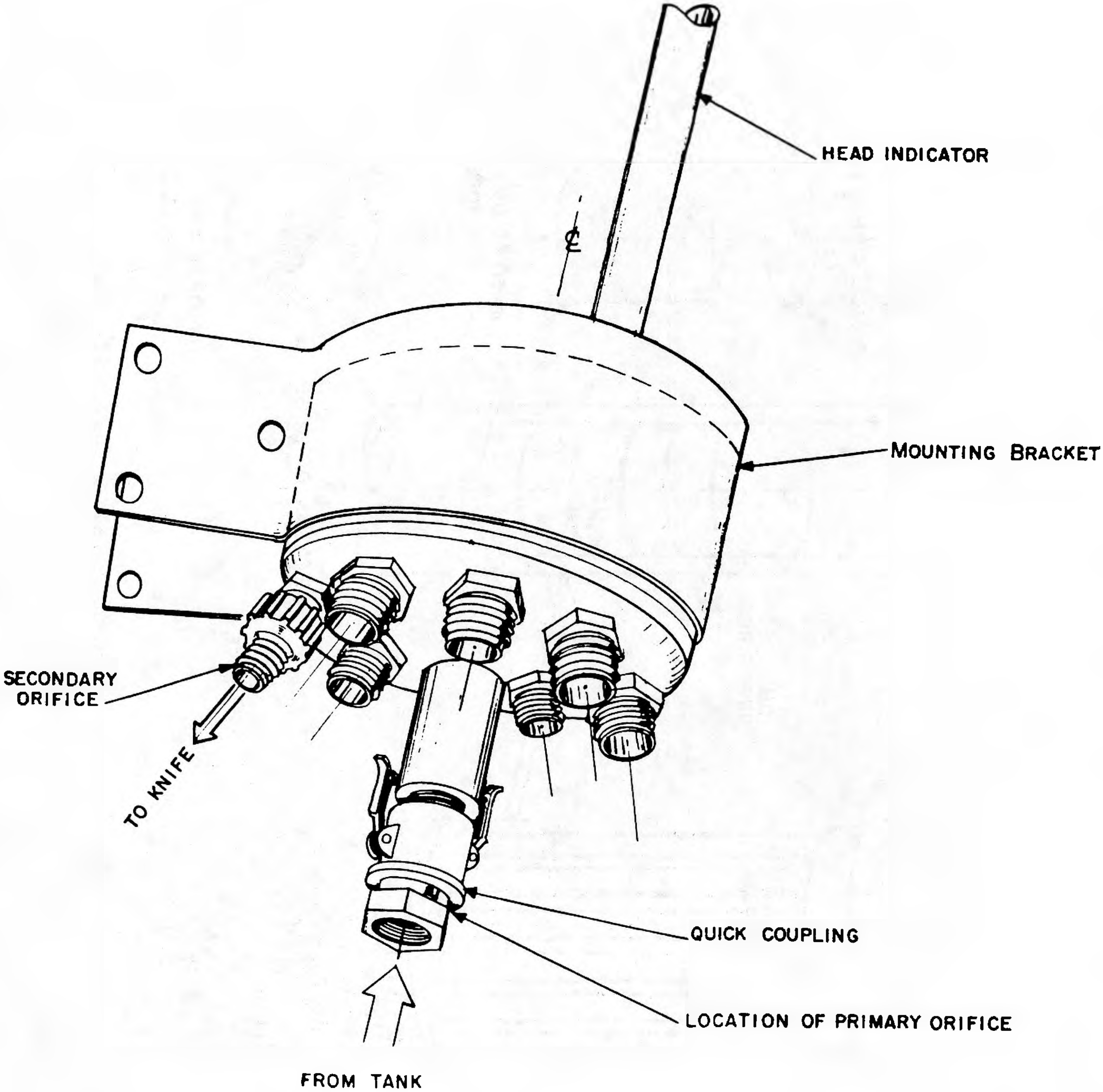

Figure 6. Distributor for subsurface placement of liquids.

Weed Interference

E. Stoller

Interference is the current term used to describe the overall effects of neighboring plants on one another's growth. In this discussion, we are concerned with the detrimental effects of weeds on crops. Interference comprises (1) competition, which is the weed's disproportionate acquisition of one or more growth factors such as light, nutrients, or water that is detrimental to the growth of the crop; (2) allelopathy, which is the harmful (or stimulative) effect of the weed on the crop through the production of chemicals that affect crop growth; (3) parasitic interference, the process in which one weed lives on the crop and obtains food from the crop while contributing nothing to the crop's survival; and (4) indirect interference, which is the harmful effect(s) that the weed brings to the crop, such as harboring an insect that attacks the crop.

The major interest in weed interference relates to the losses they cause by infesting crops. Weeds can cause losses to producers through interference by lowering crop quality and by hindering the harvest operation. In addition, weeds are aesthetically unpleasant and can cause health problems. Most of the economic losses from weed infestations are a result of interference, but decisions about whether to control weeds are not always based on economic considerations. When considering weed control options, the threshold concept has been used. Most often, the concept of thresholds relates to crop yield losses and weed density, but other connotations of the term are also relevant. A damage threshold is a minimum density of weeds that damage soybeans, which translates into a statistically significant reduction in crop yield (with research techniques currently used, a 10-percent reduction). An economic threshold is the minimum weed density at which control measures should be implemented to avoid economic loss. An aesthetic threshold is the minimum weed density that the producer (or landlord) will accept. Often, the aesthetic threshold is below the economic threshold.

There is much more research reported on weed interference in soybeans than in corn. Reports of various densities of a single species that interferes for the entire season reveal that the following general order of severity (the most severe species listed first) for weeds in soybeans is: Jerusalem artichoke, common cocklebur, velvetleaf, volunteer corn, smooth pigweed, jimsonweed, shattercane, tall morningglory, and giant foxtail. In corn, the severity is as follows: common cocklebur, shattercane, giant foxtail, and common lambsquarters.

There are two types of experiments commonly conducted regarding the yield losses experienced with less than full-season weed interference. One type simulates the conditions when soil-applied herbicides are used at planting. These studies evaluate the length of time that a herbicide must maintain activity to avert yield loss by measuring yield losses obtained from weeds that emerge at various times after planting and interfere for the rest of the season. Results show that weeds that emerge 4 to 6 weeks after planting will not reduce yields. Another type of study involving less than full-season interference involves the weeds and crop emerging at the same time with the weeds being killed at various times after planting to simulate the action of postemergence herbicide activity. In these studies, results show that when weeds are killed 4 to 6 weeks after emergence, no yield losses will occur.

The amount of crop yield losses that will occur depends on the weed species that infests a crop, weed density, the variety of crop planted, cultural practices, and the environmental conditions during the season. Among these factors, probably the most influential factors affecting the crop are weed density and environmental factors.

Update on Sudden Death Syndrome of Soybeans

W. Kirby

Sudden death syndrome (SDS) is the name of a disorder of soybeans known to affect plants throughout the Mississippi River drainage. The name is somewhat misleading since plants do not die suddenly, but rather progress through a defined series of symptoms.

SDS has been known in Illinois since 1979, but became an important contribution to yield losses beginning in 1982. Field reports from southern Illinois indicate that yield losses could be as high as 46 percent in severely diseased areas. Fortunately, the average loss is far below this, ranging from about 5 to 15 percent. Factors influencing the level of yield loss include time of planting, maturity group, rainfall, temperature, and variety.

The causal agent of SDS has yet to be conclusively identified. Research currently points to a fungus in the genus *Fusarium* as the most likely candidate. Greenhouse and lab trials with this fungus have produced SDS-like symptoms in inoculated plants. However, field trials have yet to be conducted to determine the exact role this fungus plays in the SDS complex.

Research on SDS at the University of Illinois has centered on the potential use of soil fungicides to control the disease. In addition, the role of planting data (early versus late) on a known SDS-susceptible variety was also evaluated.

Field trials have been conducted in several southern Illinois counties during the past three years. Selective soil treatments, including a chemical sterilant, were applied at recommended rates, and disease progress was monitored. Weather records (temperature, rainfall, and humidity) were kept for each location to further determine the impact of these parameters on SDS development. Field sites have been established in White, Clark, Pulaski, and Gallatin counties.

An additional component of the field trials was an evaluation of the role of soybean cyst nematode (SCN) in SDS development. Soil samples were collected at different growth stages from each of the plots, and all cysts, eggs, and juvenile nematodes were counted.

After 2 years of testing, it appears that soil fungicides do not offer a means of controlling SDS. Slight improvements in yields were recorded for PCNB, a fungicide used primarily to control *Rhizoctonia* diseases in southern crops such as cotton. Even the fungicide that selectively controls *Fusarium* fungi had virtually no effect.

The only material to control SDS completely was methyl bromide, the soil sterilant. No disease was seen in plots treated with this chemical. However, the high cost (around $1,200/acre) precludes the use of methyl bromide in soybeans.

Soybean cyst nematode levels, while extremely variable at the different locations, did not significantly impact the SDS level. Disease was found where low to high levels of SCN existed with no correlation to the nematode population levels.

In summary, SDS continues to be an elusive disease complex. It is greatly influenced by a multitude of factors including agronomic and environmental ones. It appears that, for the immediate future, no control measures can be offered beyond selection of the best agronomic practices suitable for soybeans in the given productive area.

Limiting Potential Hazards from Pesticides with What You Wear

M. Sohn

Of the three routes of pesticide entry into the human body (dermal, oral, and respiratory), the dermal route is the most common means of pesticide exposure and absorption. Research (Wolfe et al. 1967, Gold et al. 1982, Mailbach et al. 1971) has shown that dermal exposure accounts for 87 percent of the total human exposure to pesticides. Dermal exposure may result from direct contact of the pesticide to the skin or from absorption of the chemical by clothing, which transfers it to the skin. In addition, dermal exposure could occur from wearing unlaundered or inadequately laundered contaminated garments (Lavy et al. 1983). Dermal pesticide exposure poses a potential health hazard because it involves absorption of chemicals through the skin where it may be disseminated throughout the entire body via the blood stream.

Clothing can reduce skin exposure to pesticides and provide protection for those who work with these chemicals. However, there is no one type of clothing that is right for all situations. The type of protection needed depends on many factors, including the toxicity of the pesticide; the type of exposure that results from the work activity, formulation and concentration of the pesticide, and the equipment used; and how readily different areas of the body absorb the pesticide.

Specialized protective clothing is available for use by pesticide workers. These garments are generally classified as disposable or reusable garments. Two types of specialized clothing are spunbonded disposables and rubberized rainwear. Each has its advantages and disadvantages.

One of the spunbonded disposables on the market is Tyvek® (manufacturer's trade name). Researchers have found that the nonpunctured type of Tyvek® provides an effective barrier to many pesticide sprays and dusts. Although Tyvek® has been found to be a launderable disposable, recent research results indicate a concern that pesticide contaminants can be deposited on the inside of the garment in the laundry process. These spunbonded garments are relatively inexpensive. However, in field test studies, wearers have judged these garments uncomfortable in hot weather.

Composites that coat the regular structure or laminate a layer to it are a variation of spunbonded fabrics. One example is Saranex® (manufacturer's trade name) which is a laminated Tyvek®. Studies indicate that it provides better protection against several chemicals than the polyethylene-coated Tyvek®. The composites are more expensive than regular spunbonded disposables but have similar discomfort characteristics when worn in hot weather.

Rubberized cotton rainwear is another type of specialized protective garment. Studies have shown that it provides excellent protection, even against spills of liquid concentrates (Staiff et al. 1982). Rubberized rainwear is more expensive than spunbonded disposable clothing. However, it is reusable and can be cleaned by hosing it off. Disadvantages include its heavier weight and bulk, as well as being uncomfortable to wear due to the added warmth factor.

Although these special protective garments are available, recent surveys indicate that the majority of farmers and commercial applicators do not wear them. Reasons stated for not wearing these garments include thermal discomfort, discomfort due to design, cost of the garments, lack of availability, and doubt that they are needed for protective benefits.

All clothing is protective to some extent. It is the degree of protection provided by the garment that is important. Few specific recommendations concerning clothing have been made by regulatory agencies. Instead, farmers have been advised to follow label directions for the specific pesticide they plan to use. Label recommendations vary but tend to recommend use of various protective clothing items. Occupational Safety and Health Administration (OSHA) Standard 1910.267a suggests that protective clothing include a "washable fabric." Recommendations for laundering, if given, are often vague and state that pesticide-contaminated clothing should be laundered with soap or detergent.

A North Central Region (NCR) textile research project that addresses some of these problems and concerns was recently completed. One part of this project was a survey of farm families in five states (Rucker et al. 1988). The survey was conducted to determine attitudes and practices regarding pesticide application and protective clothing. The states included in this survey were Iowa, Michigan, Minnesota, Oklahoma, and California. Researchers found that the majority of respondents in each state wore long-sleeved shirts and jeans or work pants during application. The majority of respondents in each state also indicated that they wore leather shoes and company or baseball caps. This finding offers particular concern because these types of items have a tendency to absorb and hold pesticide next to the skin. Few applicators in any of the states reported wearing such items as waterproof jackets, pants, and boots. The majority of applicators indicated they did not reuse pesticide-soiled garments without laundering them after each use. In general, the majority of the respondents in each state assumed that whatever they wore protected them from pesticide exposure and that pesticide seldom or never got through clothing to their skin. Also, the majority of the respondents viewed both immediate and long-term health problems from pesticides coming in contact with their skin as not likely to happen; and, if such problems did occur, they believed the results would not be serious.

The research project also focused on the effectiveness of work clothing fabrics as protective barriers against dermal exposure to pesticide chemicals and on effective cleaning methods for decontaminating these fabrics (Raheel et al. 1988). Data documenting the dermal protection provided by work clothing fabrics and information on effective methods for cleaning pesticide contaminants from these reusable types of garments have been limited.

The NCR textile scientists investigated the effect of fiber content, fabric geometry, and use of functional finishes on the absorbency and transfer of pesticides from the surface of traditional work clothing fabrics (garments) to underlayer garments or skin. Pesticides used in the research study represented pesticide classes widely used on crops in each researcher's state.

Traditional work clothing fabrics of cotton and cotton/polyester blends were used in the majority of the studies. Acrylic, nylon, and olefin fabrics were also tested. Fabrics were tested with and without water-repellent (fluorocarbon) finishes. Formulations of pesticides investigated included flowable water-soluble concentrates, emulsifiable concentrates, wettable powders, and encapsulated pesticides. Pesticides were prepared according to label recommendations for conventional use or alternate use concentrations.

Results of the pesticide penetration and transmission studies of traditional work clothing fabrics showed that less pesticide was transmitted through 100-percent cotton and polyester/cotton blend fabrics than through 100-percent synthetic woven fabrics. Although the lightweight fabric (broadcloth) had the lowest absorbency, it also exhibited a very rapid rate of wicking and a potential for greater pesticide penetration. Less penetration was exhibited in heavyweight fabrics such as twill. Researchers also found that treatment of traditional work clothing with a consumer-applied, renewable, fluorochemical, soil-repellent finish inhibited pesticide absorption and permeation. However, this finish retained effectiveness through only two launderings and then needed to be reapplied.

NCR researchers focused on laundering procedures to decrease and deactivate pesticide contaminants on clothing. Conclusions based on findings of the refurbishing methods studies were:

1. Buildup of pesticide residue in fabrics, when clothing was not laundered daily, was difficult to remove.
2. Prerinsing of contaminated fabrics effectively reduced the amount of pesticide residue in fabrics after laundering.
3. Several studies indicated that two or more launderings were more effective in reducing pesticide residue than one laundering.
4. Hot- and warm-water washes were found to be equally effective in removal of pesticide contaminants for most of the pesticides included in these studies. Cold-water wash was not effective.
5. High- or low-phosphate granular detergents were quite effective in removing wettable powder, flowable water-soluble concentrate, and encapsulated formulations of pesticides. In some cases, heavy-duty liquid detergents were more effective in removal of residue when emulsifiable concentrate was the pesticide contaminant.
6. Use of laundry additives, such as bleach or ammonia, did not improve removal of pesticide residue.
7. Transfer of pesticide residue from contaminated clothing to other textile items in the same laundry load was observed. Also, contamination of laundry equipment was noted. Accidental exposure of applicator families could occur via handling of contaminated clothing in the laundry process and pesticide transfer in laundering.
8. Researchers found that ease of removal of pesticide contaminant was not always a function of pesticide solubility. Formulations of pesticides affected removal of pesticide in varying degrees.

Results of the NCR research project and other studies are the basis for a number of recommendations for use and handling of clothing in pesticide application.

Special protective clothing provides an excellent barrier against pesticide penetration. These garments worn over traditional work clothing provide extra protection, particularly when mixing and loading pesticides. An alternative would be the use of consumer-applied soil-repellent fluorocarbon finish on traditional work clothing to provide dermal protection from pesticide contaminants. The renewable soil-repellent finish must be reapplied after every second laundering.

Multilayered clothing, such as a knit undershirt under a traditional work shirt, appears to offer greater protection. Garments of 100-percent synthetic fiber, such as shirts and pants, should not be worn when pesticide applicators are handling pesticide.

Recommendations for handling clothing worn when working with pesticides include changing clothing daily and storing contaminated clothing separately from family laundry. Contaminated disposable clothing and any garments that are fully saturated with highly concentrated or highly toxic pesticide should be discarded in the same manner recommended for disposal of the pesticide container. Garments soiled by low-toxicity pesticides can be laundered safely, even if soiling is extensive.

Pesticide-soiled clothing should be laundered the same day that it is contaminated. Wear rubber gloves to handle pesticide-soiled garments. Garments should be presoaked or prerinsed before laundering. Launder only garments contaminated with the same pesticide together. Use hot or warm wash water rather than cold water. Wash only a few garments at a time, using the "full" water-level setting on the washer. Use a normal 12- to 14-minute wash cycle and double rinse; use heavy-duty granular phosphate detergent or heavy-duty liquid detergent. Line dry laundered garments to avoid possible transfer of contaminants to the dryer.

Clean the washing machine to reduce pesticide residue levels before washing other family wash loads. To do this, fill the washer with hot water, add detergent, and let machine run through the wash and rinse cycles.

The problem of reducing pesticide exposure is very complex. Fabrics vary in many ways and so do pesticides. Many of the possible combinations of fabric, laundering, pesticide, and exposure situations have not been studied. There is also a need for research in the development and evaluation of protective clothing that is consistent with users' physical, psychological, and economic needs.

These and many other areas of concern in the relationship of clothing, pesticides, and pesticide users offer continued challenges to textile and apparel researchers. Possibly, an equal challenge is to successfully determine effective methods for disseminating the research findings to all those persons who need the information to help them limit potential hazards from pesticides.

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Retail Dealers' Responsibilities Under OSHA's Hazard Communication Standard

V. Thompson

On May 23, 1988, the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) expanded the Hazard Communication Standard (29 CFR 1910.1200) to cover all employers in the nonmanufacturing sector. Prior to the expansion, only the manufacturing sector was covered. Agrichemical dealers, custom applicators, and other small businesses with employees who handle or are exposed to hazardous chemicals are now required to comply with this federal regulation. The Hazard Communication Standard (HCS) is also known as "Employee Right-to-Know."

The following overview of the Hazard Communication Standard and compliance requirements is oriented towards agricultural chemical dealers to aid in developing their hazard communication program. It is not intended as an official compliance guide.

REGULATION OVERVIEW

The federal Hazard Communication Standard establishes uniform requirements for determining the hazards of all chemicals produced, imported, or used in U.S. workplaces, and ensures that the hazard information is transmitted to affected employers and exposed employees.

Chemical manufacturers and importers must evaluate the hazards of the chemicals they produce or import and convey hazard information to downstream employers and distributors by means of labels on containers and material safety data sheets (MSDS). Downstream distributors must also ensure that labels are intact and pass on MSDS's.

Employers are required to have a hazard communication program and to provide the hazard information to their employees by container labeling and other forms of warning, MSDS's, and training. An employer is covered by the standard if employee(s) are exposed to a hazardous chemicals in the workplace. Employees must receive information and training if they may be exposed to a hazardous chemical under normal conditions of use or in a foreseeable emergency.

PURPOSE AND INTENT

The purpose of HCS is to ensure that all employers receive the hazard information necessary to inform and train their employees properly and to design and put in place employee protection programs. It also is intended to provide the necessary hazard information to employees so they can participate in and support the protective measures instituted in their workplaces. The result will be a safer and healthier work environment with reduced incidence of chemical source illnesses and injuries.

COMPLIANCE SUMMARY

Agrichemical dealers, as employers and as distributors when selling chemicals to other employers, are required to comply with provisions of the Hazard Communication Standard. A dealer must have a written hazardous communication program, a list of all hazardous chemicals in the workplace and an MSDS for each, labels or appropriate hazard warnings on containers, and an employee training program. In addition, employees must be informed of hazards present in non-routine tasks, and outside contractors must be informed of hazards their employees may be exposed to while working on the site. As distributors, dealers must make MSDS's available to other employers.

Documentation of programs, employee training, content of training, and requests for missing MSDS's are all important records for a compliance evaluation. Performance and results are what OSHA is looking for and, with seasonal employees, the records may be the only evidence of compliance.

The HCS has no requirements for reports to OSHA, but Sections 311 and 312, Title III of the Superfund Amendment and Reauthorization Act (SARA), require reporting of any OSHA-identified hazardous chemical that requires an MSDS under the HCS, if inventory has exceeded threshold planning quantities.

INSPECTIONS

Federal guidelines for an OSHA inspection instruct the compliance officer to first review the written hazard communication program and then ascertain if the elements of the program have been implemented in the workplace. Employee interviews may be conducted to see if employees are aware of the HCS and the written program, have received training, have access to information and MSDS's, and are generally familiar with the hazardous properties of the chemicals in the workplace. Also of interest will be the protective measures being implemented and if employees are aware of appropriate utilization of personal protective equipment.

PENALTIES

OSHA can impose civil penalties up to $10,000 for willful noncompliance, a warning citation for nonserious violations, and fines up to $1,000 for each serious violation. Failure to comply could result in liability suits by employees who suffer injuries as a result of a dealer's failure to comply. More important, compliance will help ensure that employees work in a safe and healthy environment.

IMPLEMENTING A HAZARD COMMUNICATION PROGRAM

The Hazard Communication Standard is a performance-based regulation, meaning that the objective is results--that employees are provided information and training on the hazards of the chemicals in the workplace and that they have a safe work environment. The elements of a hazard communication program are outlined below. A brief description of what the regulation requires is presented at the end of this paper. This outline can be used as a checklist to evaluate your program.

The first task is to prepare a written hazard communication program, which actually is a record of your intentions and the methods you will implement at your business. You must make a hazard determination, which is discussed in the next section, of the chemicals that you handle and make a list of those that pose a hazard to employees. The next step is to obtain an MSDS on every hazardous chemical and other information necessary to train employees. Make sure all containers have proper hazard warnings or labels and that personal protective equipment is available. Last, but most important, train all employees who may be exposed to the hazards of chemicals.

HAZARDS AND HAZARD DETERMINATION

A chemical is "hazardous" when its presence or use poses a physical hazard or a health hazard (that is, it has the capacity to produce personal injury or illness to humans through ingestion, inhalation, or absorption through any body surface). "Exposure" or "exposed" means that an employee has been subjected to a hazardous chemical in the course of employment through any route of entry and includes the potential of possible or accidental exposure.

Health hazards can cause acute illnesses (exposure symptoms coming quickly) and chronic illnesses (exposure symptoms developing slowly over time). These include chemicals that are highly toxic, carcinogenic, mutagenic, teratogenic, corrosive sensitizers, irritants, and those that can affect eyes, skin, and body organs.

Physical hazards are fire, heat, explosion, and others that could cause personal injury. These include materials that are flammable, combustible liquids, compressed gas, explosive, oxidizers, pyrophoric, and reactive (unstable).

Hazard Determination

Agrichemical dealers/distributors as downstream employers will primarily rely on hazard determination information provided by chemical manufacturers in the form of labels and MSDS's. This information will be the basis of determining the hazards of the various chemicals or products and identifying those that must be included in the hazard communication program.

The MSDS provides the information to determine the hazards of a chemical or product. An understanding of the HCS hazard criteria is necessary to effectively use the data, but for most agrichemicals the MSDS supplements and expands on the label, providing useful information.

The pesticide label is the easiest and most consistent method to use in identifying hazard toxicity levels and to convey the information to employees. The signal words DANGER, WARNING, and CAUTION on a pesticide label correspond directly to toxicity categories or levels. The toxicity levels for the signal words are: DANGER--highly toxic, WARNING--moderately toxic, and CAUTION--slightly toxic. Pesticides with these signal words, with few exceptions, have toxicity levels that make them hazardous under the HCS. The label also identifies physical hazards (for example, flammable or corrosive properties) and lists personal protective equipment and other handling precautions.

Other Hazard Evaluations

Some hazards are not covered by MSDS's. Examples of some of these are confined space entry, dust or vapors from operations or processes, maintenance on ammonia or other hazardous piping systems, and maintenance such as welding, sandblasting, and painting.

HAZARD COMMUNICATION PROGRAM REQUIREMENTS

A written hazard communication program is required for compliance with the HCS and actually becomes a written record of intentions by which compliance can be monitored. The written program outlines the elements of a specific plan and details how each part is implemented. The following are the required elements of the HCS and must be covered in the written program.

Labels and other forms of warning. All containers of hazardous chemicals in the workplace must be labeled, tagged, or marked with the identity of the hazardous chemical and must show hazard warnings appropriate for employee protection.

Material Safety Data Sheets. Maintain an MSDS for each hazardous chemical in the workplace. These must be accessible at all times to employees in their work area. As a retail distributor, post a sign to inform other employers that an MSDS is available.

List of hazardous chemicals. Keep a list or inventory of those products in the workplace that are hazardous (flammable, combustible, known carcinogens, corrosive, toxic, or irritants to skin or eyes). The chemicals used on the list should be the same ones as referenced on the MSDS's.

Employee information and training. Employees are to be provided information and training on hazardous chemicals in their work area at the time of their initial assignment and whenever a new hazard is introduced.

Information that must be provided:

- existence and requirements of the HCS
- your hazardous communications program
- hazardous chemicals present
- location and availability of the hazard communication program, a list of chemicals, and MSDS's

Training requirements include:

- methods to detect the presence of chemicals
- physical and health hazards of chemicals present
- methods to protect themselves against exposure
- details of your hazard communication program
- how to read and interpret labels and MSDS's
- location of and access to hazard information

Nonroutine Tasks. List methods used to inform employees of the hazards of nonroutine tasks and hazards with chemicals contained in unlabeled pipe.

Contractor Employees. List methods used to inform outside contractors on the hazards their employees may be exposed to while working at your facility.

REFERENCE

Federal OSHA Hazard Communication Standard, 29 CFR 1910.1200 (available from state or regional OSHA offices).

USEPA Pesticide Strategy Plan: Illinois's Response

R. Schwarberg

The development and implementation of a state pesticide strategy plan is an awesome task requiring appreciable resources. The USEPA should be sensitive to the fact that increases in general revenue funding are difficult for most states. Thus, it may be a hardship for some states to implement such a complex plan within specific time restraints. The USEPA may want to reconsider or revise its timing expectations for states' total implementation.

Nevertheless, Illinois appreciates the offer to comment on the USEPA's Aldicarb Document and Strategy Plan. Although Illinois is not one of those states outlined in the document that is required to develop a plan, we believe it is in agriculture's best interest to comment on the proposed plan in a generic sense. It is our hope that these comments can serve a dual purpose both for the Aldicarb Document and for the USEPA Strategy Plan published earlier this year.

INTRODUCTION

We agree with the USEPA that a plan should have a preface that outlines the state's philosophy on groundwater and explains what is already in place and the expected results of the plan. The introduction should also contain any memorandum of understanding among the agencies involved in the state plan or some other special means of coordinating groundwater protection.

WATER USE CLASSIFICATION

We propose a multitier classification system. As an example, this classification could consist of the following:

1. Unlimited Groundwaters: existing and potential high-quality water for which no treatment, except chlorination and fluoridation, is necessary before use.
2. Potable Groundwaters: existing and potential quality waters that require conventional treatment before domestic use.
3. General Groundwaters: water for which nondomestic use would be appropriate. Public and private drinking water usage would be technically and economically inappropriate.
4. Remedial Groundwaters: poor quality due to contamination from human activities. Both short- and long-term remediation would be necessary.
5. Naturally Limited Groundwaters: poor quality due to natural geologic conditions. Any usage would be impractical.

The USEPA Strategy Plan would apply to categories 1 and 2, "Unlimited Groundwaters" and "Potable Groundwaters." States would adopt standards for the other three classifications allowing, if possible, no further degradation that would result in downgrading of a class of water.

STANDARD SETTING AND RISKS/BENEFITS PLANS

We disagree with the use of maximum contaminant-level goals (MCLGs) and negligible risk in the absence of maximum contaminant levels (MCLs). We encourage the USEPA to expedite the development of MCLs for as many pesticides as possible. The use of MCLGs and negligible risk will, in effect, apply a zero tolerance, and zero is not scientifically measurable. Additionally, any detection limit will trigger action, and lower detection limits are developing faster than our ability to assign complete risks and benefits for a chemical. Prevention and response would be based on detection, and this could conceivably move up and down based on our ability to detect or to modify detection procedures. Further, the cost of monitoring and protecting water and of implementing remedial action based on this zero level may limit the waters targeted to be protected.

We propose that the USEPA should use MCLs where they are available or health advisories already developed as the "red light" and allow states to develop standards and/or procedures for the "yellow light." The USEPA has the resources, experience, established expertise, and access to data needed to develop risks/benefits plans. It is our opinion and recommendation that the USEPA should continue to develop risks/benefits plans for chemicals on a national scale, and allow the states to manage the impact of these risks and benefits by the use of their state plan. In essence, the state plan as outlined in this response is a predesigned risks/benefits plan utilizing best management practices.

MAPPING AND THE DRASTIC RANKING SYSTEM

The use of Heath regions in identifying areas susceptible to pesticide contamination is inappropriate. Heath regions are delineated on the following five parameters: (1) hydrogeologic system components and arrangement; (2) nature of porosity of dominant aquifer(s); (3) solubility of rock matrix; (4) storativity and transmissivity of dominant aquifer(s); and (5) nature and location of recharge/discharge areas. Heath's classification scheme provides general descriptions of hydrogeologic systems with an emphasis on aquifers. It does not describe hydrogeological features of nonaquifers (for example, thickness and properties of overlying deposits--aquitards and confining beds), important for evaluating the potential for movement of surface-applied contaminants, such as movement of pesticides to shallow aquifers. Therefore, assessment by Heath regions is not recommended.

Counties are a more appropriate geographic unit than Heath regions for conducting groundwater risk assessments because smaller regions are being assessed. However, the most appropriate assessment system, in our opinion, would delineate geographic regions on a hydrogeological and geochemical basis, not on a political unit basis. As a model, the contamination-potential maps produced by Berg, Kempton, and Cartwright (1984) could be used.

The USEPA proposes that the DRASTIC ranking system be used to evaluate groundwater susceptibility to pesticide contamination. This approach may be adequate for a nationwide assessment or may be useful in states that have not mapped groundwater susceptibility or lack the capability to do so. However, some states, such as Illinois, have such capabilities. In addition, currently available DRASTIC ratings of counties in Illinois (prepared for the USEPA-National Pesticide Survey) contain many significant errors in evaluating groundwater susceptibility in individual counties. These errors apparently are due to the use of inaccurate data on hydrogeologic conditions within the state.

We also point out that our review of the literature and discussions with representatives of the U.S. Geological Service, USDA Soil Conservation Service, and the National Well Water Association concluded that there are no scientific studies supporting the use of the topographic factor in DRASTIC. (Volume of runoff is not related to slope.) Also, scientific staff at both the Illinois State Geological Survey and the Illinois State Water Survey agree that there is no basis on which to assign rates of recharge to the water table for the various counties in the state.

There are several advantages to using state-based maps for determining susceptibility to groundwater contamination instead of using DRASTIC. Specifically:

1. A state-based map of groundwater susceptibility to pesticide contamination can delineate areas of high susceptibility that are based on hydrogeologic, rather than political unit, boundaries.

2. A state-based map of groundwater susceptibility can be prepared by state-level hydrogeologists and soil scientists who are familiar with local hydrogeologic conditions and have a perspective about which factors may be most significant for specific areas.

3. DRASTIC is weighted toward high-yield aquifers (hydraulic conductivity greater than 10^2 cm/s); however, many rural, domestic drinking water supplies withdraw groundwater from geologic formations of much lower hydraulic conductivity. The states may wish to rate these areas, which may have a relatively low DRASTIC rating, as having a high potential for pesticide contamination of drinking water sources. If the USEPA is interested in groundwater rather than aquifer contamination, other ranking systems may be more appropriate.

Neither the summary of proposed actions nor the Aldicarb Technical Support Document thoroughly outlines the application of the DRASTIC system to counties. Specific comments include:

1. The differentiation between high, medium, and low vulnerability based on DRASTIC scores has not been field tested and, as used in the stratification of counties for the National Pesticide Survey (NPS), simply reflects an arbitrary grouping of counties with various DRASTIC scores to meet the needs of the statistical design of the NPS. That is, "high" counties include approximately 25 percent of the wells in the United States; "low" counties, 25 percent; and "medium" counties, 50 percent. Although counties with low DRASTIC scores may be relatively less vulnerable to contamination than counties with high scores, there is inadequate evidence to support these high, medium, and low vulnerability groupings, based on DRASTIC scores.

2. The DRASTIC scores rate "overall vulnerability" of a county (p. ii-25, Aldicarb Technical Support Document). Consequently, a county with a significant percentage of cropland that would be highly susceptible to contamination from pesticides could have an overall medium or low rating if the majority of land area were not very susceptible to pesticide contamination.

MONITORING AND AUDIT

We propose that when states are notified by appropriate venues, such as the USEPA, of a pesticide residue in groundwater at or near "yellow light" levels and the groundwater is susceptible to further leaching of contaminants, the states would initiate a monitoring/auditing plan. This plan should be initiated in areas of the state designated as especially vulnerable using the USEPA DRASTIC model with confirmation from state mapping, as described elsewhere in this response. If the state can document the errors of DRASTIC, the USEPA should allow the states to initiate mapping their own areas of vulnerability.

The registrant should be responsible for the construction of the monitoring well and the analytical services. The location of the wells should be determined by a joint agreement between the states and the registrant. The registrant's analytical program should be approved by the USEPA and the states, indicating the proper analytical methods and adequate quality assurance procedures. All results would be submitted to the states and the USEPA regulatory office in a timely manner. The states should implement an audit plan consisting of a paper review (worksheet, etc.) of the registrant's work and sampling. The state would audit the registrant's results by analyzing random state-drawn samples in state laboratories.

ELEMENTS OF ACTION

The elements for a comprehensive best management plan should be developed in concert with standards development, state mapping, monitoring and auditing programs, and agrichemical facility site containment procedures. When analyses from monitoring wells indicate that groundwater contains a pesticide at or above "yellow light" standards, the state plan would be initiated. The state would notify the public of its findings via various legal channels.

The specific language should be independently developed by the state using its own language and procedures. The actual investigation should encompass both point sources and nonpoint sources. The elements of investigation would be, but are not limited to, containment structures, spills, improper disposal, back siphoning, chemigation, cropping practices, misuse, method of application, rate of application, and time of application. If the investigation indicated a point source contamination, the state would take steps with the facility to mitigate the problem. These steps could range from spill cleanup to closing of the facility.

If the investigation indicates that chemical application is the problem, any number of alternatives could be used, depending on availability, soil conditions, weather, and other environmental circumstances. Each solution would have to tailor fit a specific problem and may include a change in farming practices (integrated pest management, rotation, etc.), alternative chemicals, rate reduction, time limitation, and different application methods.

Increased setbacks and other wellhead protection measures would have to be determined on a case-by-case basis, depending on the type and quantity of pesticide found, soil conditions, recharge area, well construction, and terrain.

After assessing the problem and determining the best management practices to be used, the state should increase monitoring to see if the level of contamination increases or decreases. Additional action by the state would be predicated upon monitoring results. These actions should allow for area or state cancellation of a pesticide's use or the enforcement of some type of restricted use.

If state or area cancellation occurs, the state would have to develop an enforcement agenda. This agenda should at least include continued monitoring of groundwater, auditing of agrichemical dealers' records, and auditing of field applications.

REMEDIAL ACTION AND CLEANUP

The plan should allow for cleanup procedures such as the following:

1. Community wells. If pesticide contamination causes an imminent health problem in a public water system, the state EPA may use Superfund money for alternative sources of water or for cleanup of the existing problem.

2. Private wells. If pesticide contamination causes an imminent health problem in a private well, then--if possible--a new well would be constructed or an alternative source of water would be supplied. The old well would be properly abandoned.

3. Community and private wells. If possible and if the conditions warrant, the aquifer would be remediated.

4. Funding for steps 2 and 3 would have to be legislated, allowing for recouping funds from the guilty party by litigation or by the use of federal monies not now available.

METHOD OF PROMULGATION

Individual states, businesses, and the general citizenry are affected by decisions dealing with pesticides and groundwater. Therefore, it should be imperative that all parties have an opportunity to present positions, pro and con, to the USEPA on specific pesticide groundwater proposals. The best forum for this interchange of thoughts and ideas is the standard rulemaking process as opposed to special review. For this reason, the State of Illinois advocates that decision making should be channeled through the rulemaking process, allowing for due process. We recognize the extended time frame for this process as opposed to the time frame for special review, but we feel that a fair and reasonable rule would be promulgated out of this process.

Groundwater Contamination in the Vicinity of Agrichemical Mixing and Loading Facilities

T. Long

Like many other research projects, the study I describe here was the result of a chance observation. The Illinois Department of Public Health (IDPH) maintains jurisdiction over noncommunity water supplies. Over the past several years, it has been testing for the presence of pesticides and other organic and inorganic contaminants in private wells. During one week in the spring of 1987, four separate analyses of water from wells serving agrichemical mixing and loading facilities crossed my desk. The analyses showed detectable levels of pesticides in the water samples. The present study was undertaken to determine whether an ongoing problem exists at these facilities or if the initial observation had been just a fluke.

Since the initial detection of agrichemical contamination of groundwater in the late 1970s and early 1980s, the unstated assumption has been that the majority of this contamination is the result of nonpoint source pollution, surface runoff, and the leaching of materials applied to cultivated lands. This is undoubtedly true, on the whole, for the widespread, but low-level contamination of groundwater by pesticides identified so far in various states. The preliminary data from this survey, however, indicate that in terms of local groundwater quality, agrichemical facilities are potential point sources for contamination of aquifers. In certain circumstances, this point source contamination of groundwater may be more significant in terms of human exposure than that resulting from nonpoint source pollution.

Agrichemical mixing and loading facilities are very common in all agricultural states. They are so ubiquitous that, for the most part, they tend to fade into the background and remain unnoticed. Between Springfield and Chicago, there are at least 23 such facilities along the Interstate 55 right of way. Currently, there are over 1,500 agrichemical mixing and loading facilities in Illinois, based on Illinois Department of Agriculture (IDA) licensing records (information communicated by Tom Walker).

It should come as no surprise that for a number of reasons these agrichemical facilities can cause groundwater contamination. Hundreds or thousands of pounds of various pesticides, fertilizers, and other common industrial chemicals are stored on-site (Table 1), often in less than ideal conditions. Mixing, loading, and disposal practices have been, and presently may be, unmindful of potential environmental impacts. Finally, the production wells of the facilities are often shallow, improperly constructed, or poorly located with respect to ongoing storage, mixing, loading, or cleaning of chemicals. Given that 20 pounds of a compound evenly distributed in an aquifer will contaminate 10 million liters of water to a level of 100 parts per billion, the implications of years of running a high-volume agrichemical business on a small piece of land without paying proper attention to relatively obscure or poorly understood environmental issues are clear.

The facilities sampled were randomly selected from a list of over 1,500 licensed agrichemical dealers provided by the IDA. At present, approximately 80 sites from across the state have been sampled (Figure 1). Data from approximately 50 sites are available for presentation, along with some additional data from samples taken by county health departments and the Illinois Environmental Protection Agency (IEPA).

Samples were collected in solvent-rinsed gallon bottles and submitted to the Springfield IDPH laboratory for analysis. Samples were prepared by liquid/liquid extraction according to United States Environmental Protection Agency (USEPA) methods and analyzed for a variety of pesticides using gas chromatography (Table 2). Where necessary, identification was confirmed by gas chromatography/mass spectrophotometry.

Of those samples currently reported out of the laboratory, over 75 percent (43 of 56 samples) had residues of at least one pesticide. The compounds detected most frequently and at the highest concentrations are the most commonly used herbicides for soybeans and corn, and they are those that appear to be fairly mobile in the environment: alachlor, metolachlor, metribuzin, cyanazine, atrazine, trifluralin, butylate, and pendimethalin (Table 3). In some wells, the contamination was quite high; but for the most part, residues were in the low- to sub-part per billion categories. Low levels of chlordane and heptachlor epoxide, and traces of dieldrin and lindane were found in several wells. Low levels of two popular organophosphates were also detected.

The occurrence of these compounds in the groundwater beneath these sites is undoubtedly the result of past and present practices at these facilities. Back-siphonage, sloppy mixing and loading procedures, lack of rinsate collection, and improper waste disposal are possible explanations for the current situation. Contaminated soil may also continue to serve as a chemical reservoir and, through leaching, lead to constant contamination of groundwater, in spite of any changes in operational procedures at a given facility.

The level of nitrates in the wells of these facilities was also determined (Table 4). Most of these wells had levels of nitrates greater than 1 part per million (ppm). In some instances, an excessive amount of nitrates was found in individual wells. Over 60 percent of the wells tested exceeded the drinking water standard of 10 ppm. Fortunately, few if any of these wells are used as a primary source for drinking water, and none are known to furnish water for children younger than one year.

It should be noted that groundwater deterioration beneath these facilities is not necessarily due solely to pesticide and nitrate contamination. A number of samples had many peaks that were not identifiable as pesticides. For example, an analysis of a more complete sampling (volatiles, semi-volatiles, base/acid/neutral fractions, pesticides, PCBs) of one facility's well revealed a variety of organic contaminants (Table 5), perhaps the result of carrier solvents, fuels, oils, or other materials used and spilled on-site.

Despite the pesticide and nitrate contamination beneath these facilities, the potential human exposure may be limited or nonexistent in many such circumstances. Many of these facilities are isolated, and the wells are not sources of drinking water. Even when the wells are sources of potable water, they usually do not serve as the sole source of cooking and drinking water for exposed individuals.

In certain instances, however, this groundwater contamination can affect surrounding wells. In a number of small communities, agrichemical mixing and loading facilities are close to homes with private drinking-water wells. Most of these private wells are old, shallow, and poorly constructed. Thus, they are highly susceptible to deterioration due both to surface runoff and groundwater contamination. At least 10 such sites are within a 25-mile radius of Springfield. As an example of the contamination that can occur in such situations, two cases from joint IEPA/IDPH investigations are presented in Tables 6 and 7.

I understand that the IEPA has also located several small communities that have public water supplies contaminated with pesticides, presumably under similar circumstances. As a result, pesticides from mixing and loading facilities have been found in public wells and throughout water distribution systems (information communicated by A.G. Taylor).

After a drinking water supply has been found to be contaminated, the question of how to assess potential human impact arises: How much is too much? Enforceable standards or even guidelines for many of these compounds do not exist and toxicological data from which such standards might be derived often leave much to be desired. At the regulatory level, however, we often do not have the luxury of waiting for new toxicology data before making a decision regarding contamination of this sort. Decisions are often based on the best data available and are revised as necessary.

For long-term exposures (defined here as between 1 and 7 years), a commonly used approach is illustrated in Table 8. The toxicological data base is reviewed to find information that will allow a No-Observed-Effect Level (NOEL) to be derived. Because these data are usually found in feeding studies, the levels of pesticide must be converted from parts per million in the diet to milligrams of pesticide per kilogram of body weight per day using species-specific conversion factors. An Acceptable Daily Intake (ADI) is derived from the NOEL by dividing the NOEL by a safety factor selected to reflect the degree of confidence in the data. In the case of cyanazine, 1,000 was selected because the NOEL reported in a secondary source (*Herbicide Handbook*, Weed Science Society of America, 5th edition, 1983) and the actual experimental data (experimental design, results, number of animals, endpoints of concern, slope and shape of the dose-response curve, etc.) were not available for review. The ADI (or reference dose) is then adjusted to reflect consumption of contaminated drinking water by the use of appropriate body weights (70 kilograms for adults; 10 kilograms for children), amounts of water consumed daily (2 liters for adults; 1 liter for children), and the relative contribution to overall exposure to the product that its occurrence in drinking water represents (20 percent). This method was used to derive guidelines where standards or advisories were lacking.

Table 9 is a comparison of the suggested IDPH guidelines thus derived and the draft USEPA health advisories for drinking water that were received by this agency in November 1987. It should be kept in mind that the proper interpretation of such guidelines is not that, at the suggested level and above, there is danger, but rather that, at the suggested level and below, there is a reasonable assurance of relative safety to consumers. Mixtures were evaluated for potential hazard, utilizing a method borrowed from industrial hygiene and adapted for environmental exposures, as illustrated in Table 10.

Future plans for this and similar studies will include: (1) continuing the survey of agrichemical mixing and loading facilities; (2) conducting repeat sampling to monitor groundwater quality at these facilities over time; (3) determining the influence of soils, well construction, location, and chemical handling practices on groundwater quality; (4) testing of neighboring wells for pesticide residues and nitrates in water; and (5) expansion of the current program of private well testing to include random testing for common pesticides.

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Figure 1. Agrichemical facilities from which groundwater samples have been analyzed, November 1987.

Table 1. Typical Chemical Inventory of Agrichemical Facilities

AAtrex
(Atrazine)
Agrox D-L Plus
(Captan, Diazinon, Lindane)
Alfa-Tox
(Diazinon, Methoxychlor)
Ambush
(Permethrin)
Amiben
(Chloramben)
Amitrol
Aquazine
(Simizine)
Atrazine
Banvel
(Dicamba)
Basagran
(Benzaton)
Basalin
(Fluchloralin)
Bicep
(Atrazine, Metolachlor)
Bladex
(Cyanazine)
Blazer
(Acifluoren)
Brominal
(Bromoxynil)
Buctril
(Bromoxynil)
Classic
(Chlorimuron)
Command
Counter
(Terbufos)
Crossbow
(2,4-D, Triclopyr)
Cygon
(Dimethoate)
Dash
Diazinon
Disyston
(Disulfoton)
Dual
(Metolachlor)
Dyanap
(Naptalam)
Dyfonate
(Fonofos)
Embark
(Mefluidide)
Eptam
(EPTC)
Eradicane
(EPTC)
Furadan
(Carbofuran)
Fusilade
(Fluazifop-P-Butyl)
Genate
(Butylate)
Guthion
(Azinphos-Methyl)
Heartland
Hoelon
(Diclofop-Methyl)
Lasso
(Alachlor)
Lexone
(Metribuzin)
Lo-Vol 4D
(2,4-D)
Lorsban
(Chlorpyrifos)
Marksman
(Dicamba, Atrazine)
Paraquat
Pounce
(Permethrin)
Pramitol
(Prometon)
Prowl
(Pendimethalin)
Ramrod
(Propachlor)
Rescue
(Naptalam)
Reward
Ridomil
(Metalaxyl)
Rhonox
(MPCA)
Round-Up
(Glyphosate)
Salvo
(2,4-D)
Scepter
Sencor
(Metribuzin)
Sevin
(Carbaryl)
Sonalan
(Ethylfluralin)
Spectracide
(Diazinon)
Supracide
(Methidathion)
Sutan
(Butylate)
Treflan
(Trifluralin)
2,4-D
Thimet
(Phorate)
Tordon
(Picloram)
Tolban
(Profluralin)
Vernam
(Vernolate)
Vertac
(Dinoseb)
Weedone
(2,4-D)

Anhydrous ammonia
#1 Diesel fuel
Hydraulic oil
Gasoline
Motor oil
Antifreeze
Propane
Transmission oil

Table 2. Pesticides Sampled for in Survey

Acephate	Dieldrin	Metribuzin
Alachlor	Dimethoate	Naled
Aldrin	Disulfoton	O,P-DDT
Alpha-BHC	EPTC	Pendimethalin
Alpha-chlordane	Ethoprop	Phorate
Atrazine	Fenthion	Picloram
Benzaton	Fenvalerate	P,P-DDD
Bromacil	Fluchoralin	P,P-DDE
Butylate	Fonofos	P,P-DDT
Captafol	Gamma-chlordane	Propachlor
Captan	Heptachlor	Propetamphos
Chloramben	Heptachlor epoxide	Simizine
Chlorpyrifos	Isofenphos	Sumithrin
Cyanazine	Lindane	Tebuthiuron
Cypermethrin	Linuron	Terbufos
DDVP	Malathion	Triclopyr
Diazinon	Methoxychlor	Trifluralin
Dicofol	Metolachlor	

Table 3. Pesticides for Which Residues Have Been Found in Samples from Agrichemical Mixing and Loading Facilities in Illinois

Pesticide	Occurrence	Range (ppb)	Median (ppb)	Mean (ppb)	Range of the 50th percentile (ppb)
Alachlor (Lasso)	34/56	0.01-1300	5.04	118.1	1.56-62
Atrazine (AAtrex)	21/56	0.024-220	10.0	27.1	2.4-21
Butylate (Sutan)	12/56	0.16-28	8.0	11.3	2.5-20
Chlordane	25/56	0.02-1.7	0.1	0.3	0.05-0.21
Chlorpyrifos (Lorsban)	17/56	0.02-0.5	0.105	0.14	0.04-0.15
Cyanazine (Bladex)	23/56	0.04-69	2.2	11.7	0.35-15
Diazinon	5/56	0.02-1.1	0.42	0.55	0.3-0.9
Dieldrin	2/56	0.01-0.05	0.03	0.03	----
Heptachlor epoxide	13/56	0.029-0.38	0.14	0.16	0.07-0.24
Lindane	1/56	0.4	----	----	----
Metolachlor (Dual)	32/56	0.56-2100	4.05	141.9	1.48-24
Metribuzin (Sencor)	31/56	0.04-240	2.11	29.9	0.51-17
Pendimethalin (Prowl)	10/56	0.08-1300	8.6	140.3	0.6-19
Trifluralin	15/56	0.01-10	0.4	1.93	0.13-2.2

Table 4. Nitrate Content of Agrichemical Facility Wells

Pesticide	Occurrence	Range (ppb)	Median (ppb)	Mean (ppb)	Range of the 50th percentile (ppb)
Nitrate (N) in water (greater than 1 ppm)	51/56[a]	1.2-1288	25.0	107.7	10-82

[a]Of the 56 wells sampled, 35 of them (64 percent) had nitrate contamination levels that exceeded the drinking water standard (10 ppm).

Table 5. Groundwater Quality Beneath an Agrichemical Facility

Compound	Level of contamination (ppb)
Alachlor	6.75
Atrazine	4.43
Metolachlor	9.71
1-Heptene	1.38
Ethyl benzene	1.39
Xylene	15.50
Trifluralin	0.11
Trimethyl heptane	5.48
Methylene chloride	9.90
3-propoxy-1-propene	0.50
2-methyl-1-nitro propane	0.22
2-methyl-3-propyl-cis-oxirane	2.00
2-methylpropyl oxirane	2.50
Unidentified phthalate	4.50
Aliphatic hydrocarbons	39.80
Substituted fatty acid	21.90
Substituted pentane	0.01
Trichloroethylene	2.30
Tetradecane	0.03
Methyl chloroform	28.40

Table 6. Impact of Groundwater Contamination on Neighboring Wells: Case #1

Type of well and sample number	Compound	Level of contamination
Agrichemical facility	Nitrates	232 ppm
	Chlordane	0.2 ppb
	Alachlor	1.61 ppb
	Metolachlor	1.35 ppb
	Metribuzin	0.4 ppb
	Chlorpyrifos	0.16 ppb
RW-1	Nitrates	<10 ppm
	Heptachlor epoxide	0.24 ppb
	Chlordane	0.21 ppb
	Alachlor	2.6 ppb
RW-2	Nitrates	<10 ppm
	Heptachlor epoxide	0.13 ppb
	Chlordane	0.21 ppb
	Alachlor	2.43 ppb
	Metolachlor	1.43 ppb
RW-3	Nitrates	<10 ppm
	Heptachlor epoxide	0.14 ppb
	Chlordane	0.2 ppb
	Metolachlor	1.29 ppb
RW-4	Nitrates	<10 ppm
	Heptachlor epoxide	0.15 ppb
	Chlordane	0.15 ppb
	Metribuzin	2.11 ppb
SW-1	Nitrates	<10 ppm
	Alachlor	0.21 ppb
	Metolachlor	1.93 ppb

RW = residential well
SW = school well

Table 7. Impact of Groundwater Contamination on Neighboring Wells: Case #2

Agrichemical facility

Nitrates	350 ppm
Atrazine	110 ppb
Alachlor	47 ppb
Metolachlor	17 ppb
Cyanazine	57 ppb
Metribuzin	88 ppb
Butylate	0.66 ppb

RW-1

Nitrates	25 ppm
Chlordane	0.05 ppb
Atrazine	1.1 ppb
Alachlor	0.5 ppb
Metolachlor	2.2 ppb
Cyanazine	1.7 ppb
Metribuzin	0.37 ppb

RW-2

Nitrates	<10 ppb
Atrazine	0.56 ppb
Alachlor	8.4 ppb
Metolachlor	4.2 ppb
Cyanazine	0.13 ppb

RW-3

Nitrates	<10 ppm
Atrazine	10 ppb
Alachlor	68 ppb
Metolachlor	10 ppb

RW-4

Nitrates	22 ppm
Atrazine	49 ppb
Metolachlor	1.9 ppb
Metribuzin	7.5 ppb

RW-5

Nitrates	<10 ppm
Atrazine	5.3 ppb
Metribuzin	0.98 ppb

RW-6

Nitrates	82 ppm
Atrazine	14 ppb
Alachlor	41 ppb
Metolachlor	110 ppb
Cyanazine	69 ppb
Metribuzin	1.2 ppb
Trifluralin	2.8 ppb

RW-7

Nitrates	120 ppm
Metribuzin	0.084 ppb

RW-8

Nitrates	<10 ppm
Atrazine	1.8 ppb
Alachlor	3.5 ppb
Metolachlor	2.4 ppb
Cyanazine	11 ppb

RW-9

Nitrates	<10 ppm
Atrazine	2.6 ppb
Alachlor	0.31 ppb
Metolachlor	1.5 ppb
Metribuzin	0.85 ppb
Cyanazine	1.4 ppb

RW-10

Nitrates	<10 ppm
Atrazine	2.4 ppb
Alachlor	2.9 ppb
Metolachlor	10 ppb
Cyanazine	2.2 ppb
Metribuzin	0.51 ppb

RW-11

Nitrates	<10 ppm
Heptachlor epoxide	0.024 ppb
Chlordane	0.119 ppb
Metribuzin	0.15 ppb

RW = residential well

Table 8. Setting Standards for Pesticides in Water (Noncarcinogenic Endpoint): Example for Cyanazine

Step 1 Data selection

A 2-year rate study which established a nonobserved-effect level (NOEL) of 25 ppm cyanazine in the diet.

Step 2 Convert to appropriate units (mg/kg/day).

$$\frac{25 \text{ mg cyanazine/kg diet} \times 0.02 \text{ kg diet consumed daily}}{0.4 \text{ kg rate body wt}} = 1.25 \text{ mg/kg/day}$$

Step 3 Calculate acceptable daily intake (ADI) or reference dose (RFD).

1.25 mg/kg/day/1,000 = 0.00125 mg/kg/day

Step 4 Calculate drinking water equivalence for adults and children.

For adults: $$\frac{0.00125 \text{ mg/kg/day} \times 70 \text{ kg} \times 0.2}{2 \text{ liters/day}} = 8.75 \text{ mcg/liter}$$

For children: $$\frac{0.00125 \text{ mg/kg/day} \times 10 \text{ kg} \times 0.2}{1 \text{ liter/day}} = 2.5 \text{ mcg/liter}$$

Table 9. Suggested Acceptable Contaminant Levels for Long-Term Exposure

	IDPH suggested guidelines		USEPA draft health advisories	
Compound	adults	children	adults	children
Butylate	200 ppb	60 ppb	8400 ppb	2400 ppb
Atrazine	70 ppb	20 ppb	123 ppb	35 ppb
Cyanazine	9 ppb	3 ppb	46 ppb	13 ppb
Trifluralin	70 ppb	20 ppb	88 ppb	25 ppb
Metribuzin	18 ppb	5 ppb	875 ppb	200 ppb
Metolachlor	35 ppb	10 ppb	1050 ppb	300 ppb
Alachlor	35 ppb	10 ppb	2 ppb*	2 ppb*

*Based on 10E-5 carcinogenic risk assessment (lifetime).

Table 10. Hazard Evaluation of Multiple Pesticide Residues: Example for RW-9 (see Table 7)

Compound:

Atrazine	2.6 ppb
Alachlor	3.1 ppb
Metolachlor	1.5 ppb
Cyanazine	1.4 ppb
Metribuzin	0.85 ppb

Determine ratio of contaminant level to acceptable level:

Atrazine	2.6 ppb/20 ppb = 0.13
Alachlor	3.1 ppb/10 ppb = 0.31
Metolachlor	1.5 ppb/10 ppb = 0.15
Cyanazine	1.4 ppb/3 ppb = 0.47
Metribuzin	0.85 ppb/5 ppb = 0.17

Add ratios:

0.13 + 0.31 + 0.15 + 0.47 + 0.17 = 1.23

If the sum exceeds unity (1.0), the water is considered unacceptable for long-term consumption; below unity, the water is considered acceptable as a source of potable water.

Pesticide Degradation Rates at Agrichemical Spill Sites

A. Felsot and K. Dzantor

An estimated 1,500 agrichemical retail facilities are scattered throughout the state of Illinois. These facilities provide farmers with a variety of services, including the custom application of fertilizers and pesticides. Most of these chemicals are handled at one loadout location where spillage is common, resulting in the accumulation of high concentrations of hazardous chemicals. Rinsing of equipment and of empty pesticide containers also produces pesticide-contaminated discharges that can move off-site as runoff. Very similar conditions of spillage and rinseout occur on many farms, especially when the same site is used repeatedly for loading and cleanup.

Because few farmers or retailers have facilities to collect and recover pesticide wastes, groundwater, surface water, and adjacent property are placed at risk of contamination. Recent research has shown that high concentrations of pesticides degrade very slowly in soil. Prolonged persistence of a pesticide in soil increases the probability that it will leach below the root zone and migrate to groundwater (Cohen et al. 1984). Indeed, pesticide wastes at agrichemical facilities may be responsible for high levels of herbicides detected in nearby wells (Long 1988).

Herbicides and insecticides currently registered for pest control in corn and soybeans normally degrade to nontoxic levels within several months after application. For example, alachlor, metolachlor, and trifluralin were rapidly biodegraded within several months after application to a variey of soil types (Baker and Johnson 1979, Walker and Brown 1985, Savage 1973 and 1978, Braverman et al. 1986). Alachlor persistence in a silt loam soil from Iowa had a half-life of 1 to 3 weeks (Baker and Johnson 1979). Atrazine, commonly considered to be a persistent herbicide, is known to be chemically hydrolyzed to hydroxyatrazine, which is then rapidly biodegraded (Armstrong et al. 1967). The half-life of atrazine is usually less than 2 months (Baker and Johnson 1979, Avidov et al. 1985). Many soil insecticides are thought to be so susceptible to biodegradation that researchers have reported microbial adaptations that resulted in enhanced biodegradation (Felsot 1989).

Early experiments showed that high concentrations of the organophosphate insecticides parathion and azinphosmethyl were not degraded in soil as quickly as low concentrations (Wolf et al. 1973, Staiff et al. 1975). A simulated spill in the top inch of soil resulted in 95,000 parts per million (ppm) of parathion that had degraded only to approximately 15,000 ppm in 6 years. Fortunately, leaching could not be detected below 2 feet. The prolonged persistence of high concentrations of parathion was associated with a reduction of microbial populations.

Excessively high concentrations of the herbicides 2,4-D and 2,4,5-T have been studied at storage sites and in field plots where they were mixed into the soil (Young 1984). More than 2 years was required for degradation of 2,4-D to less than 10 percent of levels initially added to soil. Residues resulting from spills at storage sites were even more persistent.

High concentrations of atrazine and trifluralin (1,000 ppm) were degraded in soil significantly more slowly than low concentrations (100 ppm) (Schoen and Winterlin 1987). Little degradation of alachlor was observed in experimental soil-water disposal pits after 68 weeks of incubation (Junk et al. 1984).

Recently, herbicide-contaminated soil was land-applied (contaminated soil mixed with noncontaminated soil) to corn and soybeans to clean up a site that had received rinsewater from an adjacent agrichemical facility over many years (Felsot et al. 1988). Land application would allow the high concentrations of alachlor and metolachlor present in the contaminated soil to degrade to similar background levels as freshly applied herbicide. An experiment was designed to compare the persistence of alachlor and metolachlor in soil treated with contaminated soil and in soil treated with herbicide sprays. The initial rates of application of alachlor and metolachlor in the treatments were not significantly different. Analysis of soils 1.5 years after application, however, showed significantly higher levels of alachlor and metolachlor in the land-applied soil than in the freshly sprayed soil (Table 1). A follow-up study suggested that alachlor was more intensely adsorbed to the contaminated soil than to the freshly sprayed soil (Felsot and Dzantor, unpublished). The difference in intensity of adsorption may have reduced the uptake of the herbicides by microbial cells.

In another experiment, alachlor (formulated as Lasso 4E) was added to soil at a rate of 10,000 µg per gram of soil to simulate a herbicide spill. Microbial populations in this soil were reduced by tenfold compared to microbial populations either in untreated soil or in soil treated with recommended rates of Lasso 4E (Table 2) (Felsot and Dzantor, unpublished). Furthermore, dehydrogenase enzyme activity was inhibited in the soil receiving the high concentration of alachlor. After 180 days, approximately 90 percent of the added alachlor had dissipated from soil treated at the normal rate, but less than 40 percent had disappeared from the soil receiving the high rate.

In summary, current research has suggested that excessively high concentrations of pesticides degrade at much slower rates than normally applied amounts. The prolonged persistence may be caused by toxicity to microbial populations that reduces the number of viable cells or metabolic enzyme activity. In addition, adsorption potential of highly concentrated residues may be distinctly different than the adsorption potential of much lower concentrations. Any decrease in desorption of residues would reduce uptake by microbial cells.

Problems with prolonged persistence of herbicide residues after spills and rinseout procedures indicate a need for development of technologies for minimizing, recycling, and decontaminating pesticide wastes. Ideally, agrichemical facilities should construct state-of-the-art facilities for containing spills and recycling waste pesticides. Some facilities, however, are already contaminated and need cleanup. Soil excavation and landfilling are expensive and do not address the problem of detoxification. More permanent solutions would involve decontamination by land application, chemical treatment, or biological treatment.

*Table 1. Recovery of Alachlor (ALAC) and Metolachlor (METOLAC) 528 Days After Application of Contaminated Soil and Herbicide Sprays to Corn and Soybean Plots Adjacent to the Galesville Chemical Co.**

Herbicide treatment***	ppm recovered**			
	Corn		Soybean	
	ALAC	METOLAC	ALAC	METOLAC
Check	0.025 a	0.017 a	0.069 a	0.037 a
Freshly sprayed	0.349 a	0.077 a	0.372 a	0.109 a
Contaminated soil	1.688 b	1.987 b	0.974 b	1.101 b

*Initial rates of application were equivalent to 15 lb active ingredient per acre on the basis of alachlor concentration in the contaminated soil. Metolachlor was a constituent in the contaminated soil, but its concentration was approximately one-fourth that of alachlor.

**Mean values followed by the same letter are not significantly different at the 5-percent level, according to the Student-Newman-Keuls multiple range test.

***Contaminated soil was spread across replicate plots using a manure spreader. Fresh herbicide sprays contained alachlor and metolachlor in the same proportions as determined for the contaminated soil.

Table 2. Bacterial Biomass and Dehydrogenase Activity in Soil Treated at a Rate of 0, 10, or 10,000 μg Alachlor per Gram of Soil

Rate (ppm)	Cells per gram of soil	Dehydrogenase activity*
0	1.0×10^8	28.70
10	1.0×10^8	40.30
10,000	7.8×10^8	0.20

*μg formazan formed per gram of oven-dry soil in 24 hours.

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State-of-the-Art Facilities for Containment and Mixing Sites

M. Broder

BACKGROUND

In 1987, the U.S. Congress passed the Clean Water Act Amendments, giving states the predominant role in developing their own groundwater protection strategies. These amendments, combined with the 1986 amendments to the Safe Drinking Water Act, linked drinking water supplies with substances that could leach to groundwater after being applied. Thus, agricultural chemical use is connected by law to drinking water quality by way of groundwater. The consequence of this legislation is that regulations are being written requiring dealers to provide secondary containment around fertilizer and pesticide storage tanks. Rinsate containing traces of fertilizer or pesticide must also be collected and recycled or broadcast on fields.

Some states also require that rainfall runoff from dealer sites be collected and discharged only when analysis has found it to be free of fertilizer and pesticides. Dust collection systems may also be required at dry fertilizer facilities to prevent fertilizer from becoming airborne. Though many states have not yet passed legislation, it appears that secondary containment and rinsate collection at dealer sites will be a part of all clean water regulations. Though their use and chemical composition differ considerably, pesticides and fertilizers are grouped together and treated similarly in most groundwater regulations. Consequently, descriptions of containment and mix areas apply to both fertilizer and pesticides.

The Tennessee Valley Authority's (TVA) National Fertilizer Development Center (NFDC) has assisted some fertilizer dealers in modifying facilities to comply with new regulations. Retrofitting existing fertilizer plants can be costly and, done correctly, requires communication with local environmental officials. In working with manufacturers and environmental officials, NFDC engineers have provided practical and cost-effective solutions to containment problems.

CONTAINMENT

The first step in retrofitting a plant is to develop a plan to submit to regulatory authorities. In some cases, it is desirable to change the layout of the plant to improve traffic patterns and consolidate operations that require containment. Some dealers sample the soil prior to constructing containment facilities to establish a history of the level of fertilizer and chemicals in the soil. In one case, soil samples provided evidence that enabled a dealer to prevail in a regulatory investigation.

Most fertilizer plants modified to comply with new groundwater protection laws have predominantly handled liquid fertilizers. A typical plant has storage tanks within a concrete containment wall with a capacity of 110 percent (125 percent in some states) of the volume of the largest tank within the containment. The loadout area is paved and must be designed to collect spills as large as the largest transport truck. Loadout collection basins are generally designed to spill over or drain into the tank containment area. Otherwise, the depth of the loadout collection basin is such that vehicle access becomes difficult.

Masonry and concrete are commonly used for containment walls. Asphalt sealed with a petroleum-based resin is often used for loadout basins. Although concrete is the preferred building material, local officials have approved less costly materials. In one case, environmental officials approved the use of packed earth for the walls of a large containment area. The use of earth with a layer of bentonite clay has been proposed for large tanks built on site.

Sumps are designed to collect spills for transfer to above-ground tanks and not for long-time storage of fertilizer or pesticide rinsates. Some states restrict retention of spills or rinsates in sumps to no more than 24 or 72 hours. In California, double-walled, stainless-steel tanks with a monitoring port between the walls are used for sumps. Because they have a built-in secondary containment, these sumps are not emptied on a regular basis. Standard practice with concrete sumps is to pump the contents of the sump daily into a tank within a secondary containment. Open sumps are preferred to underground tanks or concealed pits. Either a screen or small dam is used to trap dirt and debris before they enter the sump. One novel scheme for removing solids from rinsate involves three sumps in a series. Liquid for recycling was pumped from the third sump, and the other two sumps served as solids collectors.

Rainfall or snow melt collected in containment areas can be pumped out and discharged if it is free of pesticide and fertilizers. Some dealers use a drain on containment basins to discharge rainwater; however, this is discouraged as it increases the likelihood of discharging fertilizer or pesticide. Good housekeeping is essential to permit the discharge of rainwater. Otherwise, it must be diverted by a roof, recycled into mixtures, or applied on land.

MIXING SITES

Mixing sites are often built adjacent to loadout areas and share the same containment facility. Otherwise, the guidelines for containment volume are the same as for storage tanks, namely, 110 or 125 percent of the mix tank volume. The high cost of containment and the provision that the volume must be sized according to the largest tank in the containment encourage the consolidation of the mixing and loadout sites and product storage. A well-designed containment area is large enough to have walls no higher than a curb that can be ramped for vehicle access or easily stepped over by employees.

EQUIPMENT RINSING

Rinsate from equipment washings must be collected and stored in aboveground tanks. Sumps must be emptied daily; otherwise, they are considered in-ground storage basins with no secondary containment. There are several procedures for handling rinsates to avoid contamination when recycling. Some dealers segregate rinsates by crop. Others only collect rinsates containing fertilizer and rinse equipment from applications made with pesticides in the field. Only nurse and transport equipment are rinsed at the dealership.

On-board pesticide injection systems are ideal with regard to rinsate management because they minimize the amount of equipment that comes in contact with pesticides, thus minimizing rinsate generation. The high cost of on-board injectors has impeded their adoption. Because on-board injectors can handle no more than two products simultaneously, the common practice of mixing several pesticides must be done in a separate operation. Technology is available for handling more pesticides simultaneously but at a much higher cost. Regardless of the fate of on-board injectors, mixing of pesticide and carrier will probably shift to the field to avoid the hazards of transporting pesticides in large tanks.

CONTAINING LARGE TANKS

A major problem in meeting environmental compliance regulations involves large storage tanks built on site. These tanks cannot be raised with a crane and placed within a containment. For structural purposes, they are built on sand or gravel, providing no barrier to downward movement of material that could leak undetected from the tank bottom. The cost of concrete containment is such that, in one case, an earthen dike was permitted with no barrier directly beneath the tank. In new installations, the tank can be built on a layer of sand within a concrete containment. For existing tanks, the minimum requirement may involve leak detection beneath the tank in lieu of an impervious barrier. Some states may require a barrier under the tank as part of the containment structure.

Several methods for containing leaks from the bottoms of existing tanks have been suggested. One calls for welding a false bottom inside the tank over a layer of sand. Monitoring ports would be required in the side of the tank to detect leaks in the false bottom. A similar approach uses pressurized air beneath the false bottom; leaks would be signaled by a drop in air pressure in the plenum. A third option involves a plastic liner instead of a metal false bottom. In addition to high cost, these modifications can damage the existing tank. Another shortcoming of these methods is the problem of dealing with a false bottom that leaks or the reporting of such leaks.

A fourth approach to containing large tanks involves subsurface drainage that spills into a containment basin around the tank. Equipment used by utility companies to bore under roads can be used. The containment would resemble a moat around the tank with perforated piping discharging into the moat. NFDC engineers recently designed such a system for a group of saddle-mounted tanks. Environmental officials approved the design, and the work was completed without special equipment.

PLUMBING

Underground plumbing will probably receive different treatment under regulations in different states. Some underground plumbing may be permitted without changes until it is replaced. Underground plumbing should not be considered for new installations. Some states may require that all plumbing be aboveground and inside secondary containment or placed in raceways connected to secondary containment. Containment would be sized according to the size of tanks to which the plumbing is attached. Allowances may be made for underground piping where valves can be used to isolate the piping from the tanks to which they are attached.

DRY FERTILIZER PLANTS

Regulations for dry fertilizer plants will also vary. The problem of rainfall runoff transporting fertilizer away from the site will be a major concern in some areas. In these areas, all handling operations would have to be done under a roof, or runoff would need to be collected and recycled. Air quality laws have forced dealers in some areas to install dust collectors at fertilizer transfer points. Dealers that impregnate dry fertilizer with pesticides must have secondary containment around the pesticides. As with liquid materials, dealers should minimize the amount of equipment coming in contact with pesticides by shifting impregnation from the mixer to the loadout operation or to the field with on-board impregnation systems. Pesticide residues that remain in blenders can be a source of contamination. Some dealers use limestone or potash to clean out blenders. Dealers who rinse blenders with water must collect the rinsate for reuse or disposal. A common practice for eliminating the rinsing of mix equipment is to use two mixers--one for corn and sorghum, the other for beans and cotton. In areas where tobacco is grown, a blender is reserved for tobacco weed-and-feed treatments.

SUMMARY

Retrofitting by dealerships to comply with environmental regulations is a costly proposition. Finding people with authority to approve plans is difficult in some states. Usually more than one agency must be contacted. The State Department of Agriculture and State Fertilizer and Agricultural Dealer Association can be of assistance in contacting the appropriate people. Despite the cost, environmental improvements can have unforeseen benefits. Such was the case at a dealership in an urban area where containment prevented the discharge of several thousand gallons of fertilizer. An engineer or contractor experienced in concrete construction should be consulted in the initial stages of the design. Although environmental compliance may appear to be an unnecessary burden, it provides an opportunity for the fertilizer industry to take a leadership role in protecting groundwater. Indications are that there will be more--not less--environmental regulation of fertilizer and pesticide dealers in the future.

Developing a Groundwater Protection Plan

W. Simmons

Pesticide use in the United States exceeds 1 billion pounds annually. With this amount of application, it is not terribly surprising that some of these products find their way to groundwater. Can pesticides be completely prevented from entering our underground water supplies? Probably not, but steps can be taken to lower the probability of groundwater contamination. By practicing careful handling and wellhead protection and by making informed pesticide selection, applicators can reduce the chances of groundwater contamination. Groundwater protection strategies should be a goal for all pesticide applicators.

Pesticides can contaminate groundwater during any point during their use cycle, including manufacture, distribution, storage, application, or disposal. Mishandling of pesticides prior to actual field use can lead to "point source" or entry of high concentrations of chemical directly to the groundwater. Following application, pesticides are subjected to natural processes that can either render them harmless or move them to an off-target area.

HANDLING PRECAUTIONS

Mishandling and accidental spills are the most serious and most preventable forms of pesticide introduction to the groundwater. Common sense is your best ally when trying to prevent this entry route of pesticides to the groundwater. The following precautions will help you protect your water supply.

(1) Store, mix, and load chemicals and fertilizers, and rinse spray tanks at least 200 ft from wells or surface water.

(2) Empty rinse water from containers into your spray tank.

(3) Prevent back-siphoning of spray mixes into your well by keeping the water supply hose above water level in the tank.

(4) Mix and measure accurately to avoid leftover sprays.

(5) Follow labels when disposing of pesticides and their containers.

WELLHEAD PROTECTION

Wells connect the land surface with groundwater--a great way to utilize the water resource stored below us but also a potential "short circuit" for agrichemicals. Protection of the farmstead wellhead is one of the most important components of a groundwater protection program.

(1) Inspect your well for structural damage or deterioration.

(2) How deep is your well? Shallow wells (less than 50 ft deep) are particularly sensitive to chemical contamination.

(3) Does your well have a secure lid and casing?

(4) Grade soil away from the wellhead to divert water runoff and prevent ponding near the well.

IDENTIFYING POTENTIAL HIGH-CONTAMINATION SITUATIONS

Local soil and aquifer characteristics should be considered in determining the vulnerability of groundwater to contamination by pesticides. Most vulnerable is a combination of sandy soils, high water tables, and shallow wells. Least likely to encounter problems are wells in a deep aquifer overlain by well-drained soils high in clay and organic-matter content. Clay and organic matter may "bind" many pesticides and keep them from leaching. Sandy soils may be highly permeable and permit the downward passage of water and pesticides.

Especially vulnerable are areas that have limestone geology. Limestone is a soft rock that readily dissolves, leaving large conduits for surface water to enter the groundwater. This type of formation may result in sinkholes that allow runoff water laden with pesticides to go through the soil untreated.

PESTICIDE SELECTION

More Chevrolets than Rolls Royces are involved in auto accidents every year in the United States. Does this suggest that Chevys are more dangerous or are driven by poor drivers? Not really. This statistic is due in large part to the fact that there are just more Chevys in use. The same caution must be used in interpreting information about chemicals found in the groundwater. The Environmental Protection Agency (EPA) has released a list of herbicides for which they have issued "groundwater advisories." These herbicides have been found in groundwater in one or more states. The list includes many common corn and soybean herbicides such as alachlor, metolachlor, atrazine, and metribuzin. Detections of these compounds in the groundwater are often only in the parts per billion (ppb) range, but nonetheless are positive detections. It is unreasonable to suspect that these herbicides would not move in some small amounts, given the history and magnitude of their use.

If you are preparing a herbicide plan for soil or geologic conditions that favor movement to the groundwater, you may want to select compounds that are less likely to cause a problem. Three pesticide properties affect their potential for groundwater contamination due to leaching. These are (1) persistence, (2) solubility, and (3) adsorption characteristics. Persistent pesticides resist breakdown in the soil and are therefore present and available for leaching longer than less persistent pesticides. Pesticide solubility in water may be the most important characteristic affecting leachability. Soluble compounds dissolve in water and are more apt to move with infiltrating rain or irrigation water. Adsorption refers to the ability of a pesticide to bind to soil particles. Pesticides that are strongly adsorbed are less apt to move into groundwater. Strong adsorption is generally associated with low solubility. Knowing pesticide characteristics will help determine their potential for leaching to the groundwater. If your local conditions suggest a high potential for pesticide movement to the groundwater, you may want to select chemicals that are less likely to leach.

The Plant Clinic: How We Can Help in Troubleshooting and Problem Resolution

N. Pataky

Although the Plant Clinic at the University of Illinois is managed by the Plant Pathology Department, the Clinic is a College of Agriculture clearinghouse for all plant problems. Samples are logged daily, and most of the diagnostic work is done at the Plant Clinic. All diagnostic letters are prepared by the Clinic staff. Specialists are consulted as needed in the areas of botany, entomology, horticulture, mycology, plant pathology, soils, soil fertility, virology, and weed science, to name a few. In some instances a sample will need to be referred to a private lab for more specific testing or follow-up work. This procedure provides fresher specimens and frees specialists from all the paperwork associated with logging, diagnosing, and responding to sample questions themselves. In turn, the clients are more efficiently served, and samples do not become lost in the system, waiting for the return of a specialist.

The Plant Clinic was originally organized to help the county Cooperative Extension Service advisers with the variety of plant samples that they are asked to diagnose. The county advisers handle many specimens on their own, but the Plant Clinic is necessary for further help or confirmation of a diagnosis. In this way, the Clinic helps train the adviser as well as inform specialists of new problems in the state. In return, the advisers often inform Clinic staff of current problems in the counties. The advisers are often our eyes in the state. Areas of needed research can also be identified through this process.

A great percentage of Plant Clinic samples are received directly from the agribusiness sector. This may be the most efficient route, especially if the adviser is unavailable or a specific test is requested. Remember, the Plant Clinic is only a lab facility and is limited by the sample and information received.

Funding for the Plant Clinic has been difficult. When the Clinic first opened in 1976, all specimens were handled free of charge. Early in the life of the Clinic, a partial fee system was implemented to help pay for supplies and staff salaries. It soon became evident that a complete fee system was necessary to maintain an effective service. The fees only partially support the operation of the Plant Clinic, but they do allow our doors to remain open. In 1986, an across-the-board charge was assessed, regardless of sample source. Fees remain as follows:

Diagnosis	$ 5.00
ELISA Virus ID	10.00
Pinewood Nematode Analysis	10.00
Soybean Cyst Nematode Analysis	10.00
All other nematode analyses	20.00

A positive outcome of the fee system has been fewer curiosity samples and fewer poorly prepared samples. Most of the surrounding state university plant clinics have similar fee systems in effect.

Nematode problems are difficult to diagnose, requiring special equipment and trained personnel to analyze soil extracts. Because few labs in Illinois provide this service, it is appropriate that the Plant Clinic provide a nematode analysis service. The nematode processing component of the Plant Clinic has been one of its greatest strengths. In 1986, over 1,500 samples were processed for nematodes. In 1987, the number processed was over 2,000. The Plant Clinic facility has also been used to train personnel from several private laboratories in the state. We do not consider these labs to be in competition with the Plant Clinic because we are here to serve a need until the private sector is able to meet that need.

A specialized computer program called NEMASYS has been developed and implemented for nematode reporting. This program utilizes nematode counts made in the lab, and it makes recommendations for control based on these counts and cropping history from an expert data base. Each sample is given a detailed printout and personal letter of recommendations for control. This program has proved invaluable in terms of time saved and accuracy in recommendations. It also provides a professional reporting of laboratory assays on a personal level that is important to maintain in the Extension system.

The first step in the integrated pest management approach to crop production is to identify the pest. That is probably the major role of the Plant Clinic. When the problem has been identified or narrowed to a few possibilities, control recommendations can be suggested.

Generally speaking, our clients are interested in finding the cause of plant decline or the identification of a pest. The following is a list of general areas of concern and how the Plant Clinic can or cannot help in problem diagnosis.

Aflatoxin analysis. This is a major area of concern for the 1988-1989 growing season. The Plant Clinic is not equipped to do any mycotoxin analysis. A list of private labs can be recommended.

Chemical injury. Specialists will identify chemical injury based on visual symptom expression, information, and the specimens provided. The Clinic is not equipped to do residue analysis, but it can refer appropriate samples to private labs.

Disease analysis. Culturing samples onto various selective media confirms the presence of many fungal and bacterial plant diseases. When culturing is needed, allow 7 days incubation time for the organism to grow to the point that it can be identified. In many instances, diseases can be identified without the need of culturing. Serological testing is available for a number of plant viruses. This is an area that the Plant Clinic hopes to expand in the near future.

Insect identification and injury. Insect identification is available in cooperation and consultation with agricultural entomologists at the Illinois Natural Resources Building. In many cases, samples are simply forwarded to the appropriate specialist. There is no charge for insect identification. Because insect injury often occurs in conjunction with other crop problems, specialists are consulted as needed.

Nematode analysis. Individual plant parasitic nematode species are identified with specific population counts. Thresholds for injury under various conditions can be provided, along with control recommendations. Analysis can be made on both soil and root samples. Race test kits for the soybean cyst nematode are available for use in the field at no charge.

Nutrient Analysis. A suspected nutrient imbalance can be detected in many cases through symptom expression. Specific requests for soil and/or tissue nutrient analysis should be directed to private labs. A list of such labs is available at the Plant Clinic or through county Cooperative Extension Service offices.

Plant Identification. Weeds as well as desirable plant materials can be identified, provided enough information is available. Include all plant parts, information on flowering time, flower color, growth habit, seed appearance, fall color, etc.

Most plant problems involve a number of factors working together to cause plant decline. For that reason, the Plant Clinic has integrated the services of many departments within the University and serves as a clearinghouse for most plant problems. Diagnosis is only as accurate as the information and sample provided, so accurate collection and submission of samples is essential. Remember, the Clinic staff cannot go to the site, so clients must paint a detailed picture of the situation. The following pages provide information on how to collect and submit samples to the Plant Clinic, as well as a copy of the Plant Clinic Specimen Data Form (Figure 1), to be sent with each sample, and the Nematode Soil Sample Form (Figures 2 and 3), to be sent with each nematode sample. These forms are available on request from the Plant Clinic, 1401 W. St. Mary's Road, Urbana, IL 61801, or your county Cooperative Extension Service office.

INSTRUCTION FOR COLLECTION AND SUBMISSION OF PLANT SAMPLES FOR DISEASE DIAGNOSIS

Accurate diagnosis depends on two factors: (1) the rapid receipt of a fresh and representative plant sample with observed symptoms; and (2) the completion of a Specimen Data Form for each sample.

The arrival of dead plant material or decomposed plant tissue is of little or no value in diagnosis. These samples *will not* be diagnosed. Samples that arrive without a completed Specimen Data Form will be handled as time is available for examination. Samples without any accompanying identification will be discarded.

Sample Collection

1. Disease types:

    (a) **Leaf.** Collect early and late stages of infection.

    (b) **Fleshy plant parts.** Sample with a rot disease *should not* be sent in an advanced stage of decay. Collect fresh specimens with early symptom development.

    (c) **Cankers.** Select recently produced cankers. Submit the whole cankered portion if possible, preferably with healthy wood above and below the canker.

    (d) **Wilt or general decline.** Send the entire plant, with roots, if feasible; submit several plants, from healthy to severely infected. Dig, *do not* pull, plants from the soil so diseased roots will remain intact. If the whole plant cannot be sent, select samples from areas of active symptom development. Include the intact root system if root rot is suspected.

2. If air pollution injury is suspected, the pollutant and/or possible local sources of pollutants should be noted on the Specimen Data Form.

3. Nematode-caused diseases require special attention. See *Report on Plant Disease* No. 1100 for detailed instructions on the handling and shipping of nematode-infested material. This publication is available from Extension Plant Pathology, N533 Turner Hall, 1102 S. Goodwin, Urbana, IL 61801, for 50 cents per copy.

4. For fertility-induced problems, properly taken soil samples should be sent to a private soil analysis laboratory to determine possible nutrient deficiencies and/or excesses. Soil samples are of little value in diagnosing parasitic diseases (except in nematode-caused diseases).

Sample Submission

1. Disease types:

   (a) Leaf. Press leaves between heavy paper or cardboard.

   (b) Fleshy plant parts. Wrap individually in newspaper or paper toweling and pack in a crushproof box. *Do not* add moisture to the samples.

   (c) Cankers. Wrap loosely in paper and ship in a crushproof mailing tube or box.

   (d) Wilt or general decline. If the whole plant is submitted, wrap the root ball tightly in plastic; send the entire plant in a crushproof container. Excised diseased areas should be sent as cankers would be.

2. Nematode-infested samples should be shipped as directed in *Report on Plant Disease* No. 1100.

3. If plant species or samples are mixed in the same mailing container, label each separately and keep labels away from moisture. Include a Specimen Data Form for each sample.

4. Enclose completed Specimen Data Form before mailing. Keep one copy for your files.

5. Mark container "Plant Sample--Perishable."

6. Mail sample immediately, early in the week to avoid weekend layover in a post office. Keep sample cold until it is mailed.

7. Address sample to: Plant Clinic, 1401 W. St. Mary's Road, Urbana, IL 61801.

<u>NOTE:</u> Diagnosis and recommended controls by the University of Illinois Plant Disease Clinic are based solely on the material and information submitted. The less representative the sample and the less complete the information provided, the greater the chance for misdiagnosis. Please help us to help you!

NOTE: Please complete this entire form before submitting specimen(s). This will ensure more timely and accurate diagnosis. Thank you!

Plant Clinic
St. Mary's Road
University of Illinois
Urbana, IL 61801
(217) 333-0519

PLANT CLINIC SPECIMEN DATA FORM

Date______
Plant Clinic No______
Date Received______
County ID No.______

Submitted by______ County______
Grower______ Address______
Commercial____ Home Grower____ Consultant____ Phone______

Crop or Plant______ Variety______
Do you want a weed or plant identification? yes____ no____

Appearance of Plant Parts:
Roots: normal____ poor growth____ galls or swellings____ discolored____ rotted or decayed____ other______
Stem, trunk, or branches: normal____ poor growth____ galls or swellings____ cankered____ external discoloration____
top dieback____ cracked____ rotted or decayed____ other______
Leaves: normal____ abnormal growth____ galls or swellings____ wilted____ falling prematurely____
spotted or blighted____ yellowed____ mottled____ shotholed____ other______
Fruit or flowers: normal____ abnormal growth____ spotted____ rotted____ mottled____ other______
Condition Appears: Serious____ Potentially serious____ Minor____
Distribution: Scattered plants____ Groups of plants____ Most planting____ In low areas____ Slopes____
No association with terrain____ Other______
Symptoms Appeared in Past: ____days; ____weeks; ____months.
Conditions Prior to Symptom Development: Temperature____ Rainfall____ Humidity____
Storms with high winds____ Hail____ Blowing soil____ Lightning____ Greenhouse environment____
Soil Type or Mix:______ Organic matter______% Was soil mix sterile?______
Planting History: Crop two years previous______ One year previous______
Year current crop last planted in this area______ Did problem occur previously?______
Tillage History: Two years____ Last year____ This year____

Soil Test Information______
Chemicals Applied This Year: Fertilizer______
Herbicide(s) & rates______ Type of application______
Herbicide(s) previous year______ Insecticide(s)______
Fungicide(s)______ Nematicide(s)______
Turf: Home lawn____ Park____ Fairway____ Green____ Sunny area____ Shady area____ Sodded____ Seeded____
Ornamental: Approximate age and size______ Is plant a replacement?______
If so, why was previous plant removed?______

SUSPECTED PROBLEM AND COMMENTS:

Do not write below this line — for Plant Clinic use only.

DIAGNOSIS:

Figure 1. Plant Clinic Specimen Data Form.

Clinic No. (s)
N-

NEMATODE SOIL SAMPLE FORM

University of Illinois at Urbana-Champaign
PLANT CLINIC, St. Mary's Road, Urbana, IL 61801
(217) 333-0519

Submitted by______________________ Date of Sampling______________________

Address______________________ Date Submitted______________________

County______________ Phone______________ Date Received______________________

Clinic Numbers	Number of Acres	Soil Type	Present Crop (Summer)		Previous Crop (Summer)		Crop 2 yrs ago (Summer)		Next Crop To Be Grown	Number of Nematodes	
			Crop	Variety	Crop	Variety	Crop	Variety		Cysts	Eggs
N-											
N-											
N-											
N-											
N-											
N-											
N-											
N-											
N-											
N-											

Circle Appropriate Information

Distribution of Symptoms: Scattered Clustered in Spots Uniform

Association with Terrain or Soil Type: Yes No

Weather Conditions Prior to Symptom Development —

Rainfall: Low Medium High Temperature: Low Medium High

Soil Test Information or Fertilizer Application — 2 yrs past________ 1 yr past________ Current yr________

Herbicides Applied This Year______________________

COMMENTS:

For Lab Use	Soil	Roots	Juveniles	Cysts	Comments:
Date Processed					
Date Read					

O-178

Figure 2. Nematode Soil Sample Form.

Key Points for Submitting Nematode Samples

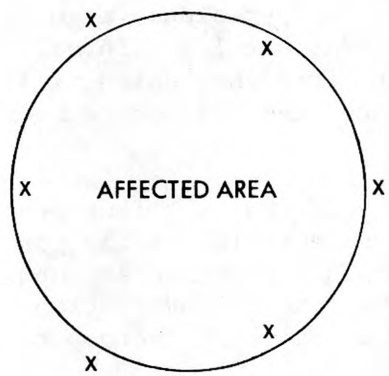
Collecting Samples

1. Take the sample from the margin of the affected areas to a depth of 8-10". When sampling from sandy soils, go to a depth of 10-12".
2. Dig several samples from the affected area, mix, and package 1 qt. of the mixed soil.
3. Include a handful of roots, including feeder roots if possible.

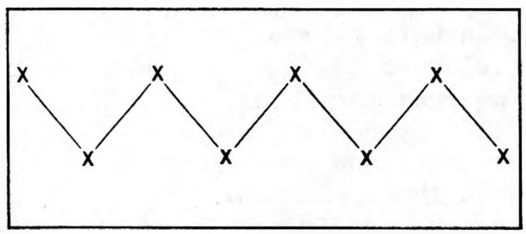
Packing and Shipping Samples

1. Use a nematode soil sample bag or a thick, sturdy plastic bag.
2. Tie the bags closed with twist ties, light wires, or use zip-lock bags.
3. Label each bag clearly and simply. Write directly on the bag or attach the label securely.
4. Place the bags in a strong container and pack them with newspaper or another insulating material.
5. Complete the reverse side of this form.
6. Ship the samples immediately, so they remain as fresh as possible. Send them early in the week to avoid drying out in weekend storage or mailing.
7. Keep the samples cool; don't allow them to dry out, but don't add water.

SAMPLING PATTERNS



HEALTHY AREA



RANDOM SAMPLING PATTERN
(5 ACRES)

Figure 3. Reverse side of Nematode Soil Sample Form.

Getting Herbicides Past Crop Residue

L. Wilbourn

The success of a conservation tillage system, the extreme of which is no tillage, depends largely on proper management, especially of pests. No-till production can be expected to have somewhat higher management requirements than conventional tillage for weeds, insects, and plant pathogens. For weed management in no-till, the farmer must rely almost totally on proper selection and use of herbicides. This reliance may mean higher herbicide usage over the crop season, especially when proper timing is not obtained.

In production systems involving cover crops or double crops, the increase in crop residue further complicates the management of crop pests. In some cases, weed control may be enhanced by the "mulch effect" when crop residue is heavy. However, this mulch can also interfere with crop growth, both physically by delaying germination and/or causing etiolation of seedlings and chemically if allelochemicals are produced.

Because the mulch alone does not usually provide adequate weed control, preemergence herbicides are applied in a manner similar to that in conventional tillage systems. Variable weed control has been reported. The reasons for this variability in weed control are not well elucidated, but it is probable that interception of applied herbicide by the crop residue plays a major role. The fate of herbicide on crop residues is subject to many factors, including the physiochemical properties of both residue and herbicide as well as environmental conditions. Foreseeable fates of herbicides on crop residues might include the following: (1) herbicide retention on the residue until a rainfall, with partial or total washoff thereafter; (2) volatilization from the residue; (3) photodecomposition on residue; (4) binding to residue; and (5) uptake by residue still capable of photosynthesis.

While the herbicide remains on the residue, any of the last four processes listed may occur. These processes depend on the characteristics of the particular herbicide, the condition of the crop residue, and environmental conditions. The amount of herbicide that washes off the residue, the redistribution of that washoff into the soil, and the potential for runoff are important factors to consider.

A field study was initiated to document interception and washoff of the preemergence herbicides, alachlor, clomazone, and metolachlor, from rye straw and corn stalk residues in no-till soybean. Some of the variables which might have important roles are: (1) type of residue (crop species); (2) state of residue decomposition; (3) timing of rainfall; (4) amount and intensity of rainfall; (5) volatilization, photodecomposition, etc., from residues; (6) application volume of herbicide; and (7) formulation of chemical. Samples of crop residue and soil were collected at 10-day intervals after application.

RESEARCH RESULTS AND DISCUSSION

In the lab, crop residue samples were washed with water followed by an organic solvent to simulate the readily available herbicide and the less available herbicide. As expected, the heaviest cover resulted in the greatest interception and least penetration to the soil surface. The majority of the intercepted herbicide that was extractable with water and organic solvent had washed off, or had otherwise been lost, by 10 days after application. The water-available chemical was similar for alachlor and clomazone except for the heaviest cover where more alachlor was available for washoff. This was probably due to the higher volatility of clomazone. For the less available herbicide (the organic solvent wash), more alachlor than clomazone was extractable, which may be due to the higher water solubility and volatility of clomazone.

From these results, we can conclude that the majority of the intercepted herbicide will be washed off the crop residue with the initial rainfall and will thus be potentially available for plant uptake. Adequate weed control will depend on the amount of herbicide available for washoff, the redistribution of washoff into the soil, and environmental factors.

Insects in Stored Corn: Updates on Insecticide Resistance and Management Alternatives

R. Weinzierl and P. Porter

ABSTRACT

Bioassays conducted in 1988 indicated that an Illinois population of the hairy fungus beetle, *Typhaea stercorea*, is resistant to the insecticides pirimiphos-methyl (Actellic) and malathion. A lab colony of the red flour beetle established from collections made in Illinois was found to be resistant to malathion, but not to pirimiphos-methyl. Several ineffective or unwise management practices currently promoted by some to replace applications of these protectant insecticides include the use of unregistered insecticides, complete reliance on fumigants, release of beneficial insects, and application of diatomaceous earth. Utilization of these management practices is discouraged. Effective pest management can be accomplished despite known resistance problems by more consistently utilizing optimum storage practices such as thorough sanitation, adequate drying, necessary aeration, and annual rollover. In combination with these practices, Actellic and malathion (plus *Bt*) remain effective against many pests when they are surface-incorporated or auger-applied where needed. Although application of Actellic or malathion will remain useful in stored-corn pest management, pest resistance makes other sound storage practices especially important.

INTRODUCTION

Most protectant insecticides and fumigants used in stored grains are expected to control a broad range of stored-product insect pests. The listings of target pests printed on the labels of two important protectant insecticides exemplify this expectation. Labels for malathion products state that this insecticide will control ten or more different stored-product pests. The Actellic (pirimiphos-methyl) label lists 15 target species. Toxicity to a broad range of insects is desirable in at least some ways because protectant insecticides are applied to control many different pests. When long-lasting residues may pose even the slightest risk to consumers, it is undesirable to have to apply a combination of several insecticides to achieve control of several different species. Because broad spectrum activity is expected from protectant insecticides used on stored grains, development of insecticide resistance in populations of even a few stored-product pests is troublesome, as the presence of pests of even a single resistant species can lead to downgrading and price discounts when corn is sold.

In the Midwest, including Illinois, widespread observations of insecticide resistance in wild populations of stored-grain pests have been confined to only two common species. Resistance of the Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae), to malathion has resulted in control failures throughout the region (Beeman et al. 1982). A selective insecticide, *Bacillus thuringiensis* or "*Bt*" (sold as Dipel, Topside, Thuricide, Bactospeine, SOK-Bt, and other trade names), is now used to protect stored grains from the Indianmeal moth. *Bt* products are poisonous only to immature stages (caterpillars) of butterflies and moths. Although McGaughey (1985) reported that lab populations of the Indianmeal moth developed resistance to *Bt*, no field studies addressing this issue have been conducted in Illinois, and resistance has not been shown to reduce the effectiveness of *Bt* in field use against this insect. Some Midwest populations of the red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae), also are resistant to malathion (Haliscak and Beeman 1983). Resistance in populations of additional stored-product insect species has been reported from other regions or countries (Champ and Dyte 1976), but Midwest populations of these species appear to remain susceptible to commonly used insecticides.

In October 1987, evidence of a new resistance problem was reported from Livingston County in northern Illinois. Heavy infestations of the hairy fungus beetle, *Typhaea stercorea* (Coleoptera: Mycetophagidae), developed in two 25,000-metric-ton (1-million-bushel) temporary storages of corn in which Actellic was applied to the grain as it was moved into storage. Residue analyses indicated that pirimiphos-methyl residues on and in samples of this corn ranged from 2.1 to 15.1 parts per million (ppm). The proliferation of hairy fungus beetles (and no other species) in these concentrations of pirimiphos-methyl provided initial evidence of resistance or species-wide tolerance in this insect. The investigations reported in this paper were undertaken to further measure and describe the insecticide failure that occurred in these storages.

MATERIALS AND METHODS

To measure and describe the response of hairy fungus beetle populations to exposure to pirimiphos-methyl, a series of bioassays was conducted. These bioassays utilized hairy fungus beetles collected from the Actellic-treated corn in Livingston County and hairy fungus beetles collected from an untreated storage in Franklin County in southern Illinois. For comparison, similar bioassays were conducted using two additional pests, the red flour beetle and the maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae). Red flour beetles and maize weevils utilized in these bioassays were taken from colonies maintained at the University of Illinois. These colonies were established using insects collected from 1984 to 1986 from untreated grain throughout Illinois. A similar series of bioassays also was conducted using malathion.

Actellic 5E or a 57-percent malathion emulsifiable concentrate was applied as a water emulsion to 97-gram corn samples in 473-ml (1-pt) glass jars. Selected dilutions were applied in 5 ml of water to provide deposits ranging from 0 to 500 ppm on 100 grams of corn. Application rates were chosen following preliminary bioassays that bracketed appropriate concentration ranges. Each treatment (rate) was replicated four times. Following insecticide treatment, 3 grams of ground corn were added to each jar to provide a food source for the hairy fungus beetle and the red flour beetle. Approximately 48 hours after insecticides were applied to corn samples, 10 to 25 insects were added to each jar. Separate bioassays were conducted for each species. Jars were capped with nylon cloth held in place by metal (canning jar) rings. Treatments were held at approximately 26.5°C (80°F); grain moistures were similar among all treatments and averaged approximately 13 percent. After 14 days, the insects were separated from the corn using a standard 12/64 corn sieve, and mortality was assessed. Results were analyzed using POLO-PC, a probit-logit analysis program for the IBM-PC (LeOra Software, Berkeley, California, 1987).

RESULTS AND DISCUSSION

The results of probit analyses of individual bioassays are presented in Table 1. LC_{50} and LC_{95} values listed in this table indicate estimates of the concentrations (in ppm on corn) required to kill 50 and 95 percent, respectively, of the tested populations. The data presented in Table 1 clearly document the occurrence of insecticide resistance in the Livingston County hairy fungus beetle population and the University of Illinois red flour beetle colony.

LC_{50} and LC_{95} values for pirimiphos-methyl against hairy fungus beetles from the Franklin County population (presumed to be a susceptible population) were estimated at 0.54 and 1.53 ppm, respectively. Estimates of these values for the Livingston County population were 20.64 and 131.86 ppm, respectively. Calculations based on these estimates indicate resistance ratios (lethal concentration for the resistant population divided by the lethal concentration for the susceptible population) of 38 and 86 at the LC_{50} and LC_{95} levels, respectively. The concentration needed to provide even 50-percent control of this population (20.64 ppm) far exceeds registered application rates, which result in maximum residues of 6 to 8 ppm on corn.

The Livingston County population of hairy fungus beetles also exhibited resistance to malathion. LC_{50} and LC_{95} values for malathion against hairy fungus beetles from Franklin County were estimated at 3.57 and 8.01 ppm, respectively. In contrast, estimates of these values for the Livingston County population were 234 and 909 ppm, respectively. Malathion resistance ratios for the Livingston County population at the LC_{50} and the LC_{95} levels were 66 and 113, respectively.

Resistance to both malathion and pirimiphos-methyl in the Livingston County population of the hairy fungus beetle leads to questions about the possibility of cross-resistance to both compounds resulting from a single resistance mechanism. (See Weinzierl 1988a for a discussion of cross-resistance and multiple resistance.) Cross-resistance is suggested in part by the fact that pirimiphos-methyl (as Actellic) was first used in the United States in the fall of 1986. It seems unlikely that an independent mechanism for resistance to this compound developed after only one year's use, although such a phenomenon is definitely possible. It seems more likely that many years of malathion use may have selected a malathion resistance mechanism that also confers resistance to pirimiphos-methyl. No data have been generated to support this hypothesis. Regardless of mechanism, however, the resistance of this population of hairy fungus beetles to both pirimiphos-methyl and malathion presents a serious problem.

Another important finding presented in Table 1 is the occurrence of malathion resistance in the University of Illinois lab colony of red flour beetles. LC_{50} and LC_{95} values for these malathion bioassays were estimated at 40 and 318 ppm, respectively. A 1- to 3-ppm malathion residue is typically effective against susceptible red flour beetles (Strong et al. 1967). Red flour beetles used in this study were collected from untreated corn in farm storages mostly in northern Illinois. The colony had been maintained in the lab on unbleached flour since 1985. Red flour beetle resistance to malathion is very stable (Beeman and Nanis 1986); hence, the resistance level observed in these bioassays may be the result of persistence of resistance from field collections. Another possible explanation for resistance in the lab population is selection by exposures to malathion residues in the wheat flour on which this colony has been maintained, but such strong selection from this type of exposure seems unlikely.

This malathion-resistant red flour beetle population does not appear to be resistant to Actellic. Although no other population of red flour beetles was bioassayed to provide comparative values, the pirimiphos-methyl LC_{50} and LC_{95} estimates for the lab colony red flour beetles do not differ substantially from similar estimates for lab colony maize weevils or the Franklin County (susceptible) population of the hairy fungus beetle. These observations indicate that the mechanism of malathion resistance in this red flour beetle population does not confer cross-resistance to pirimiphos-methyl.

Because this is the first report of hairy fungus beetle resistance to pirimiphos-methyl and malathion, it is especially important to place these findings in perspective. Resistance in this species does detract from the universal efficacy of these insecticides as grain protectants, but it does not render them useless. In a two-year evaluation of malathion (plus *Bt* for Indianmeal moth control) and Actellic as protectants of farm-stored corn in Illinois, applications made according to label directions were very effective for more than one year. In most of the bins in that study (completed in the fall of 1988), grain moistures were relatively low (most less than 13 percent). Low moistures inhibit the buildup of species such as the hairy fungus beetle, larger black flour beetle, foreign grain beetle, and other species that prefer high-moisture, moldy corn. In these bins, storing dry corn helped to control any invasions of hairy fungus beetles, even if populations resistant to pirimiphos-methyl were present.

RESPONDING TO RESISTANCE: RECOMMENDATIONS FOR 1989

Insecticide resistance in Indianmeal moth, red flour beetle, and hairy fungus beetle populations in Illinois signals a need to reconsider the methods available to manage stored-product insect pests. Complete reliance on Actellic or malathion clearly will not adequately control every storage insect problem. A summary of appropriate and inappropriate management tactics follows.

In outlining pest management practices that will be effective even though some insecticide resistance problems exist, it is probably important to first discuss actions that should not be taken. One response to resistance problems is to look for other effective pesticides. For stored corn, no other registered protectants adequately substitute for Actellic or malathion in providing long-term protection against weevils and other beetles. Reldan (chlorpyrifos-methyl) is registered for use on wheat to control these pests, but Reldan cannot legally be used on corn. It is extremely important that farmers and grain handlers do not treat corn with Reldan or other insecticides not labeled for use on stored corn. The illegal residues resulting from such use may present health risks to consumers, and such residues certainly will damage the agricultural community's image as responsible users of pesticides and suppliers of safe, healthy foods.

A second inappropriate response to stored-grain insects' resistance to protectant insecticides is to switch to complete reliance on fumigants. This approach is unwise for at least three reasons. First, fumigants provide immediate control of an existing problem, but they do not provide any subsequent protection. Complete reliance on fumigants for long-term storage requires repeated fumigations. Second, resistance to fumigants can also develop (Champ and Dyte 1976, Taylor and Halliday 1986). Fumigant resistance is most likely to develop when fumigations are conducted repeatedly and frequently in the same grain mass. A third reason not to rely too greatly on fumigants involves their hazards and the regulations that govern their use. Fumigants are extremely toxic, Restricted-Use pesticides. Fumigant applicators must wear appropriate and expensive respiratory protection equipment (often including a self-contained breathing apparatus) and use gas detection devices to monitor fumigant concentrations during applications. They also must measure gas concentrations after a fumigation has been completed to ensure that the fumigant has been exhausted from the grain mass. Regulations governing the use of currently registered fumigants require that applicators be trained specifically in the use of these products. *This requirement for fumigation training now covers private applicators.* In Illinois, private applicators who wish to purchase and use grain fumigants must pass an examination covering grain storage practices, general pest management in stored grains, and safe and effective fumigant application. Relying entirely upon fumigants is not wise, cheap, or convenient.

During the last year, there has been a great increase in interest in the use of beneficial insects (predators and parasites of pest species) for pest management in stored grains. At least one company is marketing a program that calls for periodic releases of beneficial insects in grain storages. These releases typically include three species of parasitic wasps and one Hemipteran predator.

This application of biological control has been researched by scientists at the USDA Stored-Products Insects Research and Development Laboratory in Savannah, Georgia (and by other researchers elsewhere) and reviewed by Arbogast (1984), but several key questions remain unanswered. Most importantly, despite a few testimonials, no research has demonstrated that beneficial insect releases can keep pest populations low enough in farm or commercial storage situations. Available data provide estimates of efficacy in small closed containers where pest densities were high, but no published studies have indicated that releases in farm or commercial scale storages can limit pest densities to levels that will avoid discounts based on insect infestation. Two more important points should influence grain handlers' expectations for beneficial insects. First, currently available beneficials will not survive in insecticide-treated grain. Where resistance allows a pest species to survive a protectant treatment and insecticide residues remain on the grain, beneficials absolutely cannot be used effectively to control that pest. Second, none of the insects marketed for release in stored grain will attack adult beetles or weevils. Weevils and other beetles are long-lived as adults (some up to 6 or 8 months) and remain active in grain despite the presence of the beneficial species. Release of beneficials will not "clean up" existing infestations that include adult beetles. Because the effectiveness of beneficial releases in stored grain has not been demonstrated and because the legality of releasing beneficial insects into grain remains unclear, such a program is not recommended.

Another "nonchemical" product marketed vigorously during the last year is diatomaceous earth. Diatomaceous earth is an abrasive and slightly sorptive dust that damages an insect's body covering and causes death by dehydration. Applied at high rates (approximately 2 to 5 kilograms per metric ton or 120 to 300 pounds per 1,000 bushels of grain), diatomaceous earth is a fairly effective protectant against several stored-grain insects (Quinlan and Berndt 1966, LaHue 1970). For long-term protection of grain, diatomaceous earth must be applied at the auger as grain is binned; this provides necessary uniform distribution of diatomaceous earth throughout the grain in the storage. Problems associated with the use of diatomaceous earth include increased wear to grain-moving equipment, the generation of great amounts of airborne dust during grain handling, and possible reductions in grain grade. Some buyers refuse to accept grain treated with diatomaceous earth. Because of these limitations, diatomaceous earth is not recommended for use in most grain storage situations. One successful and practical use of diatomaceous earth is its addition to small seed packets to prevent infestation by stored-product insects.

One new insecticide, methoprene (trade name Diacon), has recently been registered for use in stored grains (but not in soybeans) and may be useful in some storage situations. Methoprene, an "insect growth regulator," is a compound similar to the naturally occurring juvenile hormones of insects. It interferes with the growth and maturation of immature insects. Methoprene will not control adult insects already present in grain, but it will prevent insects in immature stages from developing into adults and reproducing. Insects listed on the Diacon label include the Indianmeal moth, cigarette beetle, lesser grain borer, sawtoothed grain beetle, merchant grain beetle, red flour beetle, and confused flour beetle. Current labeling for Diacon allows its use as an empty-bin spray and as direct spray on grain as it is augered or conveyed into storage. No instructions for surface topdress application are provided. Because methoprene does not kill adult insects, this compound should not be used to provide rapid control of existing infestations.

The information contained in the preceding paragraphs indicates that there are no single, simple solutions or replacement compounds to utilize in all situations to control the insects that have developed resistance to malathion and/or Actellic. Several effective management practices still exist, however.

Cultural practices probably provide the greatest benefit in managing insecticide-resistant pests in stored grains. Effective storage practices include bin sanitation, adequate drying, removal of fine material (broken kernels and weed seeds), aeration for temperature management, and annual rollover of grain supplies (replacing "old" grain with the current year's "new" crop). Emptying and cleaning bins before adding a new crop prevents unnecessary contamination by pests remaining in the carryover grain. Adequate drying (to about 13 percent) and removal of fine material eliminate the food sources (molds and fines) that support many of the beetles commonly found in grain. Fall and winter aeration provide consistent temperatures within a grain mass and prevent convection currents and moisture migration that result in condensation and mold growth at the surface of a grain mass. Preventing mold growth, in turn, limits infestation by mold-feeding insects. In Illinois, severe infestations rarely develop in stored corn until the end of the first year of storage (often in August or September). Limiting storage to 1 year or less often avoids the need for extensive efforts in insect management.

If corn is to remain in storage for nearly a full year (until August or September of the year following harvest), surface-incorporated treatments of malathion plus *Bt* or of Actellic alone are still recommended. These applications will inexpensively prevent infestations by weevils, most other beetles, and the Indianmeal moth. Long-term storage (for more than 1 year) is discouraged, but where this practice is necessary, auger applications of malathion or Actellic are still effective against many pests. To improve the success of long-term storage, remember that storing dry grain with a minimum of fine material will inhibit the development of hairy fungus beetles and red flour beetles, even though populations of these pests exhibit insecticide resistance.

More complete information concerning insect management in stored grains is provided in University of Illinois Cooperative Extension Service Extension Circular 1242, *1989 Insect Pest Management Guide for Stored Grain* (Weinzierl 1988b).

Table 1. LC_{50} and LC_{95} Estimates (and 95-percent Confidence Limits[a]) Expressed in ppm Applied to Corn for Pirimiphos-Methyl (Actellic) and Malathion Bioassays Utilizing the Hairy Fungus Beetle, the Red Flour Beetle, and the Maize Weevil.

Insect		Actellic	Malathion
Hairy fungus beetle (Franklin Co.)	LC_{50}	0.54 (0.31-0.70)	3.57 (2.45-4.52)
	LC_{95}	1.53 (1.12-3.66)	8.01 (6.06-15.29)
Hairy fungus beetle (Livingston Co.)	LC_{50}	20.64 (11.06-32.94)	234.46 (118.4-335.2)
	LC_{95}	131.86 (71.47-502.8)	909.01 (550.9-5427.9)
Red flour beetle (Univ. Ill. colony)	LC_{50}	0.72 (0.62-0.82)	40.10 (33.65-48.68)
	LC_{95}	1.24 (1.05-1.67)	317.81 (216.4-539.9)
Maize weevil (Univ. Ill. colony)	LC_{50}	0.42 (0.26-0.61)	1.39 (1.17-1.76)
	LC_{95}	1.33 (0.84-4.18)	3.34 (2.44-5.78)

[a]Each LC_{50} and LC_{95} value presented in this table is an estimate based on bioassay data. There is a 95-percent probability that the true population value corresponding to each estimate lies with the upper and lower limits indicated in parentheses.

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Fungicides for Control of Grain Storage Molds

D. White

The State of Illinois was once again granted a Section 18 emergency exemption under the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act for Mertect 340F, used for suppressing the growth of storage molds of corn grain. This is the third year in which such an exemption has been issued to the State of Illinois from the Federal EPA. The application of a fungicide to grain following harvest is an effective control of storage fungi if infection (establishment inside the host) by storage fungi has not already occurred and when the fungicide is used in conjunction with other control techniques such as drying, avoidance of physical damage, and cool temperatures during the winter months.

In order to understand how fungicides fit into an integrated control program for storage molds of corn, it is necessary to understand the biology of the fungi that cause deterioration of grain during low-temperature drying and storage. The deterioration of grain in storage is predominantly due to the growth of species of *Aspergillus* and *Penicillium* in corn kernels. In the presence of favorable temperatures, some species of these fungi will grow at moisture levels as low as 13.1 percent. As storage molds grow in the kernels, they produce metabolic heat and moisture that results in an increase of temperature and moisture in the grain mass. As temperature and moisture increase in the grain mass, conditions become favorable for the growth of many different fungi. Fungal mycellium and spores will be produced on the surface of rotted kernels; fungal mycellium from rotted kernels may grow into adjacent healthy kernels; and spores may be carried by air movement to other kernels where they will germinate and penetrate healthy kernels.

Storage molds that are ultimately a problem in stored corn are not usually associated with corn kernels at harvest. These fungi grow best in low-moisture environments that are associated with dead plant material and soil. *Penicillium* spp. are usually favored by cool, wetter conditions and *Aspergillus* spp. by warmer, dryer conditions. During most growing seasons, spores produced by *Penicillium* spp. and *Aspergillus* spp.--growing in association with dead plant material and soil--are spread to grain during combining of the crop. Additional spores are spread to corn kernels during aeration, blending of grain, etc. The spores will then germinate and penetrate the corn kernels whenever temperature and moisture conditions are favorable.

Storage fungi, in some environments, may infect corn kernels prior to harvest. During most growing seasons, some storage molds are found in association with small kernels at the tip of the ear following insect or bird injury. The number of infected kernels during most years is usually less than 1 percent at harvest and has little effect on the storability of the crop. During drought years, however, the number of kernels infected by storage molds at harvest is greatly increased, and will have an effect on the storability of the crop. Hot, dry weather favors storage molds in several ways. Most storage molds will grow as saprophytes in association with dead plant material, and, during dry conditions, the amount of dead plant material in the field is usually increased. Species of

Aspergillus (including *A. flavus*) will grow much better with the higher temperatures that also occur during drought. In fact, *Aspergillus flavus* will grow on dead silks and may grow into the ear if conditions are extremely hot and dry. In addition to favoring growth of storage molds in the field, dry weather also favors some insects that will cause damage to kernels; and damaged kernels on an ear are more subject to infection by storage fungi.

The drought conditions that occurred in 1988 provided an excellent environment for production of high amounts of inoculum of a number of storage fungi, with *Aspergillus flavus* being the most prevalent. The high levels of infection by *Aspergillus flavus* at harvest present a problem with regard to control of storage fungi by all techniques, including the use of low rates of a fungicide. A number of potential questions and answers concerning the storage of drought-stressed corn with high levels of infection (due to *Aspergillus flavus* and other storage fungi) are discussed below.

USE OF FUNGICIDES ON DROUGHT-DAMAGED CORN

A major concern is the effectiveness of fungicides on corn when storage molds have already infected the kernels prior to harvest. Fungicides are effective only in preventing infection or establishment of the storage fungus in the kernel. Basically, the fungicide acts as a barrier against penetration of the kernel by fungi. A fungicide does not kill the fungus after it has penetrated the kernel and begun to grow. Therefore, if corn is treated with Mertect 340F, the fungicide will protect only those kernels that are not already infected by storage fungi. The effectiveness of the fungicide will be greatly reduced as the number of infected kernels increases in the grain. It is believed, however, that the fungicide will be effective in preventing additional infections of kernels in storage. It should be remembered that the fungicide will not kill the fungus after it has infected the corn kernel; if the corn kernel is already infected with *Aspergillus flavus*, aflatoxin may be produced even in the presence of Mertect 340F. It is unlikely, therefore, that Mertect 340F will be very effective in the control of aflatoxin in grain if a high percentage of kernels have already been infected by the fungus. I certainly do not believe that we should be recommending Mertect 340F to prevent aflatoxin formation; it would be unrealistic to believe that the fungicide would reduce aflatoxin contamination in grain. Preliminary results of studies at the University of Illinois have shown that infection of additional kernels by *Aspergillus flavus* is reduced by Mertect 340F.

Grain moisture

The most powerful control of storage fungi in grain is low grain moisture. With a drought-stressed crop that has high levels of physically damaged kernels, as well as kernels infected by storage fungi, management of grain moisture becomes even more important. During this past fall, fungi that are normally found only in year-old corn kernels were found at harvest. Therefore, corn produced in 1988 will have a shorter-than-normal storage life. Drying of grain to a lower moisture level will be one control to be used with drought-damaged corn. I would suggest that a moisture of 13.5 percent would be a safe storage moisture. Even grain at 13.5 percent may have problems because if an average moisture of 13.5 percent is present in the grain mass, the moisture of individual kernels could be as high as 15.5 percent. With a moisture of 15.5 percent in some kernels in the bin, the fungus may start to develop and create metabolic heat and moisture--especially if those kernels are already infected by storage fungus.

Grain cleaning

Grain cleaning is not often mentioned as a potential control of storage fungi. It is, however, a fairly effective method for removing those kernels at the tip of the ear that have probably been infected by storage molds. Grain cleaning will result in lowering the inoculum of certain of the storage fungi and will also provide for much better aeration. It is also effective in removing those kernels at the tip of the ear that were infected by *Aspergillus flavus;* and grain cleaning may actually reduce the total aflatoxin level of the grain.

COOL TEMPERATURES

One very reliable control for storage fungi in much of Illinois is the use of cool temperatures when grain is stored during the winter months. Cool temperatures do not favor fungal growth, and corn can often be stored at a higher moisture in the presence of such cool temperatures. This year, however, cool temperatures may not be as effective as they are in normal years because of the high levels of infection by storage fungi. Therefore, bins should be monitored very carefully for detection of hot spots.

CONCLUSIONS

Drought-stressed corn grain is extremely difficult to store. All the control techniques must be utilized appropriately in order to be successful.

Deposition Efficiency from Application of Postemergence Herbicides

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Postemergence ground applications of a combination of Tandem and atrazine herbicides plus crop oil concentrate have been used for a number of years to control a broad spectrum of grass and broadleaf weeds in corn. However, aerial applications of this herbicide combination have not been made because of the lack of consistent experimentation and data to warrant label approval. This study was conducted to determine optimum aerial application parameters to maximize the deposit of these herbicides on small weed and grass plants.

The objectives of the study were to determine the effects of application rate, nozzle orientation, and air speed on the percent deposit of active ingredient and biological control of grass plants; to compare the collection of active ingredient on various artificial targets and small yellow foxtail plants; and to determine the effects of treatment variables on spray droplet size.

MATERIALS AND METHODS

Spray applications were made with a Cessna Ag-Husky aircraft set up and calibrated to obtain specified treatment parameters; spray application rates were 2 and 5 gallons per acre (gpa), air speeds were 90 and 130 mph, and nozzle orientations were 0 and 90 degrees (back and down, respectively). The aircraft was flown directly into the wind, and air speed was monitored with a radar gun. Wind direction and speed, temperature, and humidity were recorded during each test.

The sample collectors were placed between the center lines of two adjacent flight passes. Two complete sample lines were set up 50 ft apart. The upwind sample line consisted of 5 water-sensitive cards, 17 mylar plates, 5 straw stands (containing 10 polyethylene straws each), and 5 flats of yellow foxtail placed 5 ft apart and between the two center lines of the two flight paths. The second downwind sample line contained 17 mylar cards and 5 foxtail flats.

The 8- by 12-inch flats of yellow foxtail were grown in a greenhouse and had population densities ranging from 225 to 1,200 plants/ft^2. Grass growth was between the one- and three-leaf stage when applications were made. Biological response (percent yellow foxtail control) from each test was rated at 7 and 14 days after treatment (DAT).

Tandem-atrazine at 0.5 and 1.5 lb of active ingredient per acre (a.i./A), Agri-Dex, and a fluorescent dye (acid yellow #7) were mixed in water to obtain the proper application rate. Following application of each treatment, the plants and artificial targets were collected and transported to the laboratory for processing and analysis. The dye tracer was removed from each surface, and the concentration was determined by fluorometric analysis. The active ingredient deposited on each surface was expressed as a percentage of the active ingredient applied.

Droplet size spectrums from each of the test conditions were measured with an imaging spectrometer. A high-speed centrifugal blower fitted with a converging transition duct was used to direct the high-speed airstream across an airfoil-shaped spray boom with the nozzle mounted at the proper orientation. A Particle Measuring Systems, Inc., OAP-2D-GA1 laser droplet imaging probe and a PDPS 11-C data acquisition system were used to collect the droplet size information. The probe is an optical array spectrometer with 62 equal size classes ranging from 19 to 1,675 microns (μm), with a class width of about 27 μm for each size class. Tests for each parameter were run using water only and the two Tandem-atrazine concentrations. All test conditions were replicated three times and the resulting droplet size distribution data were averaged.

RESULTS AND DISCUSSION

Deposits on Mylar Plates

Treatment means for percent deposit on the mylar plates for the eight treatments are shown in Table 1. Application rate and air speed had a significant effect on the percent deposit. The 5-gpa rate and 90-mph air speed resulted in higher deposits on the mylar plates than the 2-gpa and 130-mph treatments. The reduction in deposits, when speed was increased from 90 to 130 mph, was greater at the 2-gpa rate than at the 5-gpa rate.

There was significant interaction among the variables. At 90 mph, the percent deposit for the 5-gpa rate was the same for both nozzle orientations, but at the 2-gpa rate, the deposit was higher for the 0^{o} nozzle orientation as compared to the 90^{o} orientation.

Deposits on Artificial Targets and Plants

Normalized treatment means for deposit ($\mu l/cm^2$) on mylar plates, soda straws, and yellow foxtail plants are shown in Table 2. Analysis of the mylar plate data showed significant differences in application rate and air speed as discussed earlier. The only significant factor influencing deposits on soda straws was nozzle orientation, with 90^{o} giving higher deposits than the 0^{o} orientation. Application rate, nozzle orientation, and air speed all significantly influenced deposit on plant leaf surfaces, but their interactions were not significant. The 5-gpa rate resulted in more deposit than the 2-gpa rate; the 90^{o} nozzle orientation resulted in more deposit than the 0^{o} orientation; and the 130-mph air speed resulted in higher deposits than the 90-mph air speed.

Correlations were computed for spray deposits on the three collectors. The correlation coefficient (R^2) between yellow foxtail plants and straws was 0.58; for yellow foxtail and mylar plates, the R^2 was 0.54; and the R^2 for straws and mylar plates was 0.64. This indicates that it is difficult to predict deposits on small grass plants from artificial targets.

The droplet images on horizontal and vertical water-sensitive cards were analyzed by computerized image analysis. Analysis of variance of the percent coverage on the horizontal cards indicated that rate and the rate-by-speed interaction were significant. The coverage was low for all treatments, ranging from 2.1 to 4.9 percent. Coverage on the vertical water sensitive cards was higher (9.4 to 12.4 percent) with the 5-gpa rate, 90^{o} orientation, and 130-mph air speed giving the greatest coverage.

Plant Desiccation

After treatments were applied to the flats of yellow foxtail, they were returned to the greenhouse where they were held for plant response ratings. Three to four days after application, the plants that were on the upwind side of the flats during the spray applications began to desiccate. Desiccation decreased from the upwind side to the downwind side of the flat. This reflects a filtering effect by the plants on the upwind side of the flat that would not normally be present in a field application situation. Mean plant desiccation 7 and 14 DAT was 89 and 97 percent, respectively.

Application rate was significant at 7 DAT with the 5-gpa rate resulting in better plant kill than the 2-gpa rate (Table 3). Control was significantly better when the nozzles were pointed straight back (0^{o}) compared with the nozzle pointed down (90^{o}). The 130-mph air speed resulted in the best control but was not significantly different from the 90-mph applications.

There was a significant interaction between nozzle orientation and application rate. Significantly improved control was obtained at 5 gpa with the nozzles at 0^{o}; control was the same at 5 gpa with the nozzles at 90^{o} as at 2 gpa with the nozzles at 0^{o}; the lowest control was obtained at 2 gpa with the nozzles at 90^{o}.

Trends of plant kill indicated improved control when applying 5 gpa with the nozzles pointed back. Poorest control occurred at 2 gpa and 90 mph or at 5 gpa and 90 mph with the nozzles at 90^{o}.

Droplet Size

The average droplet spectrums for water and a spray mixture of Tandem-atrazine with crop oil are characterized in Tables 4 and 5. Averages for the main effect variables (Table 4) indicate that air speed had the greatest effect on droplet sizes. Increasing air speed from 90 to 130 mph decreased the volume median diameter ($D_{V0.5}$) by 21 percent for water and 34 percent for the Tandem-atrazine spray mixture. The increase in smaller droplets produced at the high air speed nearly doubled the percent volume <204 µm for water and nearly quadrupled the percent volume <204 µm for the Tandem-atrazine spray mixture.

Changing the nozzle orientation from 0 to 90^{o} produced a 21 percent decrease in $D_{V0.5}$ for water and a 30 percent decrease for the Tandem-atrazine spray mixture. Differences in percent volume <204 µm due to changing the nozzle orientation from 0 to 90^{o} were similar to those obtained by changing air speed from 90 to 130 mph. Decreasing the application rate from 5 to 2 gpa decreased the $D_{V0.5}$ by 14 percent for water while it increased the $D_{V0.5}$ by 6 percent for the Tandem-atrazine spray mixture.

Droplet size was affected by the interaction of nozzle orientation, air speed, and application rate. Droplet sizes produced with the Tandem-atrazine mixture ranged from a $D_{V0.5}$ of 521 µm at 0^{o}, 90 mph, and 2 gpa, to 229 µm at 90^{o}, 130 mph, and 2 gpa (Table 5). At a nozzle orientation of 90^{o}, the $D_{V0.5}$ decreased significantly (13 to 20 percent) as application rate decreased from 5 to 2 gpa, while at 0^{o}, the $D_{V0.5}$ increased slightly (2 to 3 percent) as rate decreased from 5 to 2 gpa.

With the nozzles pointed straight back (0^o), increasing air speed from 90 to 130 mph decreased the $D_{V0.5}$ by 39 percent for both application rates. At 90^o nozzle orientation, the same increase in air speed decreased the $D_{V0.5}$ by 23 percent for 2 gpa and 30 percent for the 5-gpa application rate.

The trends in droplet spectrum characterization as measured by $D_{V0.5}$ are verified by the percent volume <204 µm data. Table 5 indicates the small fraction of small droplets produced at 0^o and 130 mph, compared to the large volume of small droplets produced at 90^o and 130 mph. There was very little difference in the percent volume of <204 µm at 0^o and 130 mph, compared to 90^o and 90 mph. The operating parameters chosen must take into account the plant coverage required versus the drift hazard when applying these chemicals.

In summary, droplet sizes produced when using Tandem-atrazine spray mixture ranged from 5 to 21 percent smaller than when spraying water, indicating the importance of using actual formulations when measuring the effects of various operational factors on droplet size and when comparing results to field control data. Air speed was the most significant variable affecting the droplet size spectrum, but there was an interaction between air speed, nozzle orientation, and application rate. At 0^o nozzle orientation, droplet size increased with decreasing application rate; at a 90^o nozzle orientation, droplet size decreased with decreasing application rate. Similar droplet spectrums can be produced by proper selection of nozzle orientation, air speed, and application rate.

Table 1. Percent deposit on Mylar Plates for Eight Application Rate, Nozzle Orientation, and Speed Treatment Combinations

Application rate (gpa)	Nozzle Orientation	Air speed (mph) 90	130
2	0°	48.8	33.2*
	90°	38.7	31.3*
5	0°	51.9	48.7*
	90°	52.1	47.6

*Values are means for two instead of three replications; one of the three replications in each of these treatments had crosswinds to the extent that no spray was deposited on several of the samplers on one side of the sampled area.

Table 2. Mean Sample Deposit in $\mu l/cm^2$ for Three Types of Collectors[a]

Rate (gpa)	Orien-tation	Air speed, mph: 90 Mylar	90 Straws	90 Plants	130 Mylar	130 Straws	130 Plants
2	0°	0.046	0.014	0.019	0.028	0.11	0.025
	90°	0.037	0.17	0.033	0.033	0.20	0.036
5	0°	0.045	0.12	0.038	0.036	0.17	0.041
	90°	0.049	0.16	0.052	0.043	0.20	0.066

[a]Means are normalized for differences in application rate.

Table 3. Percent Desiccation of Foxtail Plants 7 Days After Application

Application rate (gpa)	Nozzle orientation	Air speed (mph)	Plant desiccation (%)
2			90.3b*
5			94.2a
	0°		93.9a
	90°		90.9b
		90	91.4a
		130	93.5a

*Letters that are alike indicate the data are not significantly different at an LSD level of 5 percent.

Table 4. Droplet Sizes Produced by Three Treatment Variables When Simulating Aerial Application of Water Alone and Water-Based Spray Mixtures of Tandem with Atrazine Crop-Oil Concentrate

Application rate (gpa)	Nozzle orientation	Air speed (mph)	$D_{V0.5}$ (μm)	Volume <204 μm (%)	Volume >415 μm (%)	Relative span[a]
average of main effects for water only						
2			353	7.3	28.9	0.84
5			408	5.9	43.3	0.92
	0°		424	4.2	48.8	0.93
	90°		337	9.0	23.4	0.83
		90	426	4.8	48.1	0.94
		130	335	8.4	24.1	0.82
average of main effects for Tandem-atrazine formulation						
2			363	15.4	22.4	0.89
5			341	10.3	32.9	0.90
	0°		413	6.4	42.3	0.96
	90°		291	19.3	12.9	0.83
		90	425	5.4	45.1	0.96
		130	280	20.3	10.1	0.83

[a]Relative span = $(D_{V0.9} - D_{V0.1})/D_{V0.5}$.

Table 5. Summary of Droplet Sizes Produced by Eight Treatments When Simulating Aerial Application of Water Alone and a Water-Based Spray Mixture of Tandem-Atrazine with Crop-Oil Concentrate

Application rate (gpa)	Nozzle orientation	Air speed (mph)	$D_{V0.5}$ (µm) Tan/atr	water	Volume <204 µm, (%) Tan/atr	water
2	0°	90	521	404	3.0	4.7
	0°	130	316	381	9.0	4.1
	90°	90	299	336	11.3	8.3
	90°	130	229	289	38.3	12.2
5	0°	90	505	541	1.9	1.9
	0°	130	311	371	11.6	6.0
	90°	90	374	424	5.5	4.1
	90°	130	262	297	22.2	11.4

Selecting Adjuvants for Postemergence Herbicides

L. Wax

Postemergence herbicide usage in soybeans has been increasing in recent years. Postemergence treatments can be delayed until the weed problem is known and then applied according to the kind and density of species present at the time of application. This may allow an overall reduction in herbicide application on a given area. Several of our standard herbicides have performed very well when used in this manner in recent years, and they will likely continue to be used on increasingly large areas. In addition, several new herbicides under evaluation show great potential for selective control of weeds when used as postemergence treatments.

Postemergence treatments, when compared with soil-applied treatments, are relatively independent of soil type and the need for rainfall fairly soon after application. However, many factors influence the performance of postemergence herbicides, and they may cause a large amount of variation in results over different locations and years. Plant factors such as species and growth stage are very important, as are a host of environmental factors, including temperature, light, wind, relative humidity, and timeliness of rainfall. Additional physical variables such as equipment, water quality, and spray additives can also greatly influence the final results of the treatment. Another factor involves herbicide interactions, which sometimes occur with tank mixes and may influence the efficacy of the spray mixture.

Spray adjuvants are often used with postemergence herbicide treatments to maximize control while minimizing the variation caused by plant and environmental factors. They may do this in a variety of ways, but they usually act by some combination of improved deposition and retention on the leaves, as well as improved penetration through the leaf cuticle. These spray adjuvants include a wide variety of substances, including the traditional surfactants (surface-active agents) such as emulsifiers, wetting agents, stickers, and spreader-stickers. Most pesticide formulations include some sort of surfactant, but additional surfactant may improve efficacy of the applied spray when added to the tank mixture.

The most commonly used surfactants for this purpose are classified as nonionic. Labels usually call for a nonionic surfactant (NIS) of 75 to 80 percent active ingredients to be used at 0.25 to 0.5 percent on a volume:volume basis or 1 to 2 qt of surfactant per 100 gal of spray volume. If the spray volume is 25 gal/A, the surfactant is used at 0.5 to 1 pt/A.

Crop oils represent another type of adjuvant that can improve efficacy and reduce variability of results. Earlier phytobland crop oils contained about 1 to 2 percent emulsifier and were used at about 1 gal/A. Most currently used crop oils are a mixture of 80 to 85 percent phytobland oil plus 15 to 20 percent emulsifier, and they are used at 1 to 2 pt/A.

These mixtures are called crop oil concentrates (COC), but this terminology has been confusing for two reasons. They are petroleum-based oils used on crops, not vegetable- or crop-based oils. There has been considerable interest in the use of vegetable oils, but these have not generally performed as well as the petroleum-based oils and have typically cost more. Secondly, crop oil concentrates are not concentrated, as they contain less oil and more emulsifier or surfactant than the originals. The term "concentrate" came from the usage of 1 qt/A rather than 1 gal/A.

Crop oil concentrates have been widely used with postemergence sprays over the past decade. They are credited with improving performance and consistency of a number of postemergence herbicides, such as atrazine in corn, Fusilade and Poast in soybeans, and the post-broadleaf herbicides in soybeans.

Crop oil concentrates may cause more crop injury than nonionic surfactants, depending on the herbicide. Crop oil concentrates usually provide better weed control under droughty conditions than traditional nonionic surfactants do.

One of the most recent products is a spray adjuvant from BASF called Dash. Developed to help reduce the antagonism toward Poast in tank mixes with Basagran, Dash appears to do that, and, in addition, appears to improve overall effectiveness of these and other herbicides, perhaps due to improved retention and penetration or absorption.

Within the last several years, perhaps the most noteworthy development has been the evaluation and development of the various fertilizer additives. The most common of these is 28 percent nitrogen (N), a mixture of urea and ammonium nitrate (UAN), although the original work was with 10-34-0, an ammonium polyphosphate (APP). These products improved control of velvetleaf when used with Blazer (acifluorfen) and Basagran (bentazon) with less soybean injury than crop oil concentrates. However, for some weed species such as lambsquarters, fertilizer additives may be less effective than crop oil concentrates.

The recent trend has been to evaluate and use a combination of adjuvants together in a tank mix with one or more herbicides. More often than not, fertilizer solution such as UAN is used with a nonionic surfactant as a combination spray mixture.

Depending on how loosely one defines adjuvant, very low rates of herbicides might be considered adjuvants when added to the mixture to provide a "kicker" for added control of certain weed species. The herbicide 2,4-DB is labeled and commonly used at very low rates in postemergence soybean herbicide mixes to improve control of annual morningglory and cocklebur.

We have evaluated many of the adjuvants, both alone and in combination with a variety of herbicides over the past several years. The results indicate the overall improved consistency of postemergence applications that can be obtained with the use of spray adjuvants. The results also indicate differential responses among species and show potential for decreased control and increased unacceptable injury to the crop when indiscriminate mixing of a variety of adjuvants and herbicides occurs.

This past growing season was an especially good one for evaluation of adjuvants in our studies. Most weeds at the time of treatment were affected by the drought and were advanced in their stage of growth beyond the stage at which we would expect optimum control. There were very clear advantages to using adjuvants. And, with the drought, the postemergence treatments were more effective than most soil-applied treatments.

Exhaustive tests at various locations are being conducted by various industry groups, and by other private and public researchers, to determine the best mix of adjuvants and herbicides. In time, over a wide variety of locations and weather, these studies begin to show trends; and the data are used to develop label information. The most important source of information to select the correct adjuvant for your use is the herbicide label. You can supplement this with additional printed information provided by the herbicide manufacturer and by the public agencies. We have prepared some summary information in Table 1 that may be helpful concerning the current status of additives for use with a number of commonly used herbicides.

Thickening agents, compatibility agents, and antifoaming agents are specialty tank-mix adjuvants. Thickening agents are used to minimize drift by reducing the number of small spray droplets. They are frequently used where off-target spray is unacceptable. Compatibility agents are heavy-duty emulsifiers to maintain emulsion stability in liquid fertilizers. Most herbicide labels have testing procedures for checking tank-mix compatibility.

Table 1. Adjuvants for Herbicides

	NIS[a]	COC[a]	Dash[a]	UAN[a]	APP[a]	2.4-DB
SOYBEAN HERBICIDES						
Basagran		X[b]	X	X		X
Tackle	X	X		X	X	X
Blazer	X			X		X + NIS
Galaxy	X			X		
Storm		X				
Cobra	X	X		X		X + NIS
Reflex	X	X		X	X	X + NIS/COC
Tornado	X	X				
Poast		X	X	X + COC		
Fusilade	X	X				
Option	X	X				
Assure	X	X				
Scepter	X					
Pursuit	X					
Classic	X	X		X + NIS		
Rescue	X	X				
Rescue + Blazer/ Tackle	X	?				
CORN HERBICIDES						
Buctril	Do not use any adjuvants.					
Basagran		X				
Laddok		X				
Atrazine		X				
Bladex	X[c]					
Banvel	X					
Marksman	X					

[a]NIS = nonionic surfactant; COC = crop oil concentrate; Dash = surfactant from BASF; UAN = urea and ammonium nitrate; APP = ammonium polyphosphate (10-34-0).
[b]An "X" indicates labeled usage of a particular additive for a particular herbicide.
[c]Only if extremely droughty.

Postemergence Grass Control in Corn

R. Liebl

Control of grass is often the limiting factor to achieving satisfactory weed control in corn. Having good controls for grass weeds in corn is particularly important for success with conservation tillage systems. The problem is attributable to the lack of herbicide options available for grass control in corn. Unlike soybeans, where growers can choose between soil-applied and postemergence herbicides, most herbicides available for grass control in corn are applied preplant. Lasso, Dual, Sutan+, and Eradicane provide effective control of most annual grasses; Eradicane can also aid in the control of shattercane and johnsongrass. While Sutan+ and Eradicane have to be incorporated in the soil, Lasso and Dual can be applied without incorporation, but often are incorporated to improve control. Tandem plus atrazine is labeled for postemergence grass control in corn; however, this treatment has limited effectiveness on grasses larger than the three-leaf stage or when it is used under dry conditions.

The adoption of no-till or reduced tillage production generally rules out the use of mechanical incorporation to mix herbicides in the soil and places greater emphasis on the need for postemergence herbicides. Postemergence herbicides are needed in no-till to back up a preemergence herbicide failure (due to a lack of rain, for example), or as part of a planned weed management program. As some grass herbicides used for corn require incorporation, and because postemergence herbicides are not available to ensure control in the event of a soil-applied herbicide failure, present herbicide technology for grass control has limited usefulness in conservation tillage corn systems. Therefore, the use of conservation tillage practices may mean sacrificing grass control.

In addition to the lack of options for grass control in conservation tillage corn, herbicides currently available for grass control in corn provide only fair control of shattercane and johnsongrass. Weed management in corn would be improved by the addition of grass herbicides that have compatibility with conservation tillage and enhanced control of shattercane and johnsongrass.

In 1988, four experimental grass herbicides for use in corn were evaluated (Table 1). All four compounds are applied postemergence and have activity similar to Tandem plus atrazine when applied to small giant foxtail. However, unlike Tandem, these new herbicides provide good control of large (greater than five-leaf) grasses. In addition, these herbicides have the potential to greatly improve present control of johnsongrass and shattercane. For example, Accent provided excellent control of six-leaf giant foxtail, johnsongrass, and shattercane. KIH-2665 was similar to Accent, while Beacon and V-63596 were not as effective as the others on johnsongrass. A single year of field testing is insufficient to make any claims about the potential success of a herbicide; however, because these herbicides fill a niche in corn weed control that until now has been vacant, they are likely to make a tremendous impact on corn weed control.

Table 1. Postemergence Grass Control in Corn

Herbicide	Weed size	Percent Weed Control		
		Giant Foxtail	Johnsongrass	Shattercane
Beacon (16 g/A)	3 leaf	87	10	78
	6 leaf	67	20	86
Accent (0.75 oz/A)	3 leaf	93	99	90
	6 leaf	93	91	89
KIH2665 (0.12 lb/A)	3 leaf	94	84	90
	6 leaf	84	79	94
V-63596 (40 g/A)	3 leaf	70	10	80
	6 leaf	80	40	73
Tandem (0.5 lb/A) +	3 leaf	93	...	...
atrazine (1.5 lb/A)	6 leaf	56	...	...

Bushnell: A Case for Cross-Connection Control

E. Ackerman

INTRODUCTION

The quality of Illinois drinking water is often taken for granted. However, when potable water suddenly becomes contaminated and unfit for human consumption, the aftermath can wreak havoc on a community which is fully dependent upon and accustomed to a safe, reliable water supply. What can produce such a disruption? A "cross-connection." The term cross-connection is defined as any connection or plumbing arrangement between a potable water system and a system of lesser quality through which backflow can occur.

THE PROBLEM

Nine years of field surveys of approximately 100 agricultural chemical and fertilizer retail facilities throughout central Illinois have revealed some rather alarming facts. Frequently, bulk storage vessels for fertilizer solutions and herbicides were inadvertently directly connected to potable water-supply systems. In some instances, insecticide products were also cross-connected with drinking water systems. Thus, the potential readily exists for pesticide and fertilizer products to flow out of their intended storage vessels and into the water distribution system, exposing the unsuspecting public consumer. Because of the lack of careful planning and the absence of effective cross-connection control programs, many potable water-supply systems are vulnerable to the influx of toxic chemicals. In many cases, the untimely turning of a valve or series of valves would result in the flow of a concentrated herbicide or liquid fertilizer solution out to a residential faucet or back down into the groundwater. Some existing agricultural chemical load-out systems have even been installed with the potential and capacity to pump herbicides directly into the public water-supply distribution system.

Based upon over 200 field inspections of agricultural chemical retail facilities in Illinois, we estimate that the vast majority of the facilities inspected were cross-connected to a potable water-supply system. In several cases, it has been observed that anhydrous ammonia storage vessels were directly tied to the potable water-supply system. Such plumbing arrangements are not an uncommon occurrence and create an ominous condition. Anhydrous ammonia, with its high working pressure of 250 pounds per square inch (psi) and its unique affinity for water, is readily capable of entering a public or private water-supply system that typically operates at a much lower pressure.

THE BUSHNELL INCIDENT

Cross-connections are accidents waiting to happen. For years they may harmlessly exist until a precise sequence of events occurs to activate them. This phenomenon happened in the west-central Illinois community of Bushnell on April 28, 1988. The 3,800 residents experienced a threatening condition in their drinking water supply. The contamination initially showed up in a few residences in one portion of the town and then quickly spread to other parts of the city. Bushnell residents watched in dismay and astonishment as their kitchen faucets and other household water fixtures discharged a very unusual liquid. This liquid created a severe foaming in several kitchen sinks with the foam filling the sink and spilling over onto the floor. The liquid emitted an extremely strong pesticide odor. Unfortunately, many of the residents used the contaminated water. It was unsuspectingly used to water pets and livestock. Some residents bathed in the contaminated water and many drank it. It is difficult to realize the apprehension created for the residents of Bushnell. Schools, businesses, and a housing complex for the elderly were affected. Long lines of people waited to fill bottles with drinking water from an alternate source. Much concern, fear, confusion, and anger were prevalent among the residents of this small community.

Initial samples collected from the kitchen faucet of a local residence confirmed the presence of three herbicides in Bushnell's drinking water. Chlorobenzene and ammonia-nitrogen were also found in the water supply. Those sample results are shown in Table 1.

Table 1. Laboratory Analysis of Drinking Water Samples Collected from Bushnell Residences

Parameter	Concentration (ppm)
Alachlor	68.0
Chlorobenzene	9.1
Atrazine	2.6
Thiocarbamate	1.1
Ammonia	3.8

The herbicide contamination of Bushnell's water supply was the consequence of a cross-connection between an agricultural chemical and fertilizer retail outlet and the potable water supply. Although the introduction of herbicides into the drinking water did not seem to be an intentional act, the results were very real. One might assume that a large volume of herbicide would be required to produce such far-reaching effects; however, calculations utilizing projected water volumes and chemical concentrations demonstrate this is not the case. It is estimated that less than 2 gallons of alachlor could have caused the Bushnell incident.

CHECK VALVES NOT RELIABLE

In spite of the alluring nature of the simple check-valve device, it is not an acceptable or reliable backflow prevention device. Simple check valves can and readily do become stuck open or in some instances jammed open by a foreign object present in the water-supply system. A history of incidents (not limited to those at agricultural chemical operations) has demonstrated that the simple check valve is not a dependable device for preventing a cross-connection. For this reason, Illinois law (Illinois Pollution Control Board Rules and Regulations, Title 35: Environmental Protection, Subtitle F: Public Water Supplies) prohibits the use of a simple check valve as a means for preventing contamination of a potable water-supply system.

THE FAIL-SAFE SYSTEM

The Illinois Department of Public Health has direct authority to oversee the proper installation of cross-connection control devices. Licensed plumbing inspectors are on staff to administer their program. In addition, Illinois environmental law requires each municipality to have an active cross-connection control program. However, this does not relieve the responsibility and ultimate liability of each agricultural chemical retail operator to provide a safe facility, free of cross-connection to a potable water-supply distribution system.

The only totally reliable cross-connection control device is a fixed proper air gap, also referred to as a break tank. Figure 1 provides a sketch of such a device. Potable water is supplied through a stationary pipe, which is securely attached to the water storage tank (or break tank). The end of the water-supply pipe is fixed at a minimum distance of 6 inches above the flood level rim of the tank. It is essential that the outlet end of the water-supply pipe remain at least 6 inches above the top of the tank, and under no conditions should the pipe extend down into the break tank. All of the water utilized at the agricultural chemical facility must be routed through this minimum air gap of 6 inches.

Water from the break tank can be used to fill pesticide spray vehicles. Where additional pressure is desired, as with spray hoses for container rinsing or vehicle washing, a repumping system can be installed after the break tank. The use of the break tank system is an infallible method for safeguarding agricultural chemical and fertilizer retail facilities.

CONCLUSION

An agricultural chemical cross-connection with a public or private water-supply system is a very serious threat to public safety. Such cross-connections are frequently observed by Illinois Environmental Protection Agency personnel. The cross-connection dilemma calls for prompt, responsible action on the part of the agricultural chemical industry. A break tank system is the most reliable technology for protecting potable water supplies and is relatively simple and economical to install. The concern for safe drinking water and protection from liabilities should be sufficient incentives for rapid implementation of these safeguarding measures.

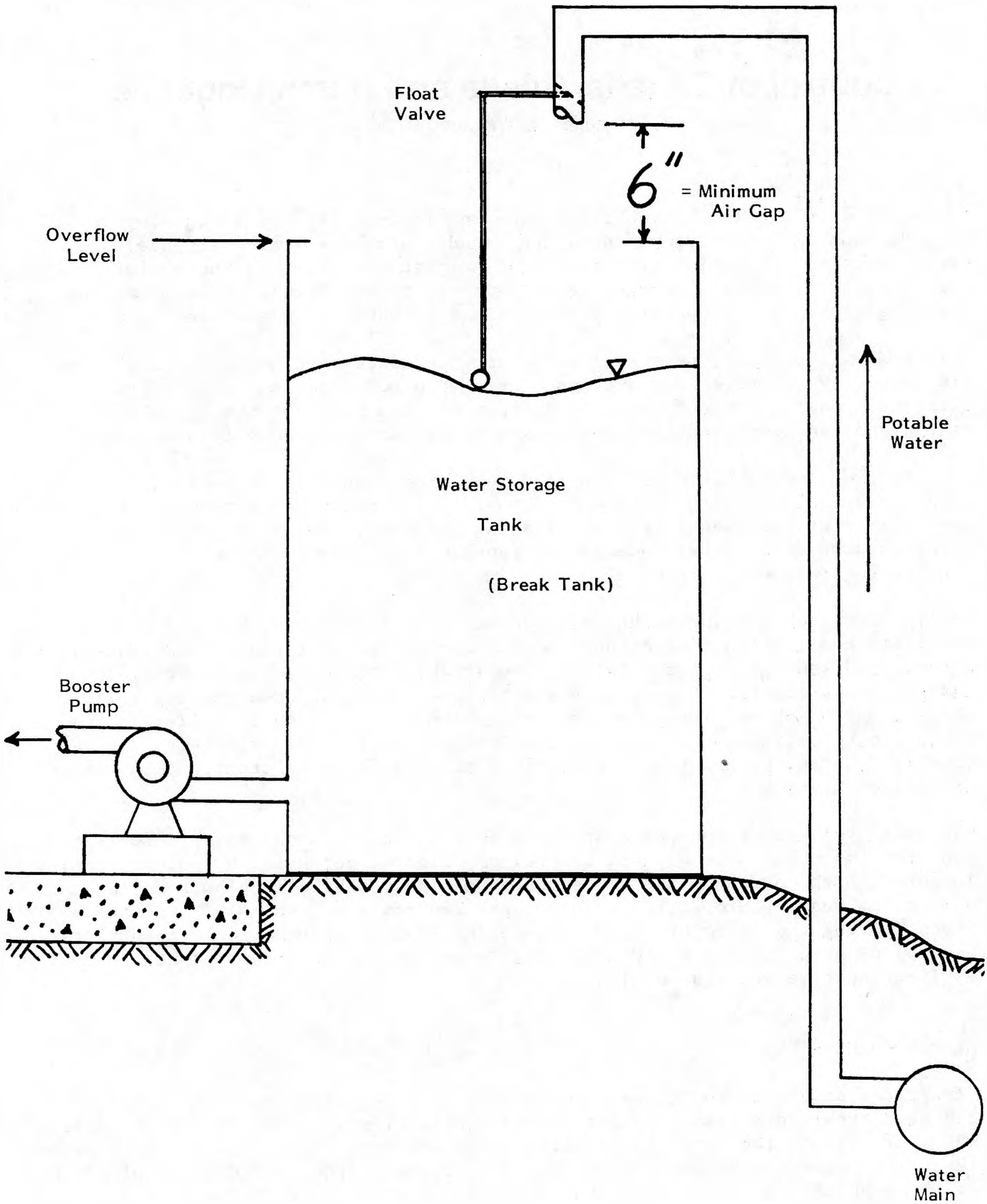

Figure 1. Potable water-supply break tank sketch.

Control of Canada Thistle and Hemp Dogbane

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Perennial weed problems have been increasing in recent years in the Corn Belt. Hemp dogbane *(Apocynum cannabinum)* and Canada thistle *(Cirsium arvense)* are examples of two perennial broadleaf species that are becoming increasingly prevalent in Illinois. Changes in tillage practices, herbicide programs, and cropping system may be partially responsible for shifts in the weed spectrum.

Unlike annual species, perennial weeds can reproduce vegetatively, as well as from seed. Vegetative reproduction occurs when buds located on underground rhizomes, tubers, or rootstocks break dormancy and produce shoots. These shoots emerge and can soon establish themselves independent of the original plant.

Many of the commonly used soil-applied herbicides can provide good control of young perennial seedlings. However, control of established perennials requires a herbicide that can translocate to existing rhizomes, rootstocks, or tubers. Complete control of these underground reproductive structures is necessary to prevent regrowth and reinfestation.

Earlier research has shown that maximum weed control can be obtained when herbicide application time coincides with the movement of photoassimilates to the underground storage organs (that is, rootstocks, rhizomes, tubers, etc.). Maximum translocation of photosynthate has been shown to occur during early fall in many perennial species. Some translocation can also occur earlier in the season, but is limited before the bud-to-bloom stage. Unfortunately, few chemical control programs are currently available for consistent and convenient control of these weeds.

Two relatively new compounds being developed by Dow Chemical may provide some hope for improved postemergence control of selected perennial broadleaf species in corn. Both compounds are believed to be highly mobile in plants and may have good translocating properties. This paper reports the results of two studies investigating the efficacy of EF-689 and XRM-3972 as postemergence treatments for control of hemp dogbane and Canada thistle in corn. The effect of herbicide application time was also evaluated.

HEMP DOGBANE STUDY

Five rates of EF-689 and three rates of XRM-3972 were compared with several standard treatments (Table 1). A prebud application was made on May 25, 1988, when corn was in the five- to six-leaf stage and hemp dogbane plants were between 12 and 28 inches in height. More than 90 percent of the hemp dogbane plants were at the prebud stage, with many shoots still emerging.

The same treatments were applied to different plots approximately 2 weeks later. Corn was in the seven- to eight-leaf stage, and hemp dogbane plants ranged from 38 to 47 inches in height. At this time, more than 75 percent of the plants were at the bud-to-bloom stage. Soil moisture conditions were considered adequate to slightly dry when the first application was made, and very dry on the second application date.

Herbicides were applied with a CO_2 backpack/hand-held sprayer operated at 34 pounds per square inch and 3 miles per hour. 8002XR flat fan nozzles were used, and the spray solution was applied in a volume equivalent to 18 gallons per acre.

The experimental design was a randomized complete block-split plot with three replications. Treatments included 24 different herbicide x application-time combinations with three different evaluation dates. The experimental unit was considered a single evaluation of a four-row plot measuring 10 x 30 feet. Evaluations were made at 2, 4, and 8 weeks after application.

Treatments and results are shown in Table 1. For both application dates, EF-689 provided good to very good seasonal control of emerged hemp dogbane at rates of 4 or more ounces of active ingredient per acre (a.i./A). With the later application, the 2.0-ounce rate of EF-689 also appeared very good. Some regrowth was observed 8 weeks after application, decreasing percent control for some treatments. XRM-3972 exhibited very little activity regardless of rate or date applied. The 8.0-ounce rate of 2,4-D amine provided fair to good control early and late, while the lower rate was somewhat disappointing. Control with dicamba was considered unsatisfactory.

In the EF-689 plots, more regrowth was seen this year than in a similar study conducted last year. Decreased translocation due to low soil-moisture levels and high temperatures could be one explanation. Another possibility might be that there is a higher degree of weed infestation at the study site this year.

CANADA THISTLE STUDY

Five rates of XRM-3972 and three rates of EF-689 were compared with several standard treatments (Table 2). A prebud application was made on May 25, 1988, when corn was in the five- to six-leaf stage and Canada thistle plants were between 3 and 9 inches in height. All plants were in the prebud stage and some were still emerging. The same treatments were applied to different plots approximately 3 weeks later. However, due to a shortage of plot area, only four rates of XRM-3972 and three rates of EF-689 were included along with the standard treatments. Herbicides were applied in the same manner as described for the hemp dogbane study. At the time of application, corn was at the 10- to 12-leaf stage and Canada thistle plants ranged from 8 to 20 inches in height. More than 75 percent of the plants were in the bud-to-bloom stage, and both corn and weeds were experiencing considerable drought stress.

The experimental design was a randomized complete block-split plot with three replications. Treatments included 26 different herbicide x application-time combinations split in time with three different evaluation dates. The experimental unit was considered a single evaluation of a three-row plot measuring 9 x 30 feet. Evaluations were made at 2, 4, and 8 weeks after application.

Treatments and results are shown in Table 2. Excellent season-long control of Canada thistle was observed only with the early application of 8.0 ounces of XRM-3972. Fair to good control was observed with the 2- and 4-ounce rates of XRM-3972 applied early and the 4- and 8-ounce rates applied late. All other treatments (including the standards) were considered unsatisfactory. EF-689 provided extremely poor control, and in some instances exhibited no activity at all. Control with the lower rates of XRM-3972 and with the standards was less than expected. It is possible that the dry weather may have affected herbicide performance, particularly with the later application.

CONCLUSIONS

EF-689 exhibits a high degree of activity on hemp dogbane, and yet very little effect on Canada thistle. Conversely, higher rates of XRM-3972 can provide very good control of Canada thistle but little help against hemp dogbane. These results underscore the fact that weed species can vary greatly in their sensitivity to different types of herbicides.

Application time did not appear to have a consistent effect upon the results obtained. A more significant effect was expected, but may have been confounded by the unusual environmental conditions.

Table 1. Control of Hemp Dogbane

Herbicide[a]	Rate oz a.i./A	Application time[b]	Hemp dogbane control[c] weeks after application 2	4	8
			........*percent*........		
EF-689	0.5	1	53	80	72
		2	52	69	78
EF-689	1.0	1	68	79	68
		2	76	86	84
EF-689	2.0	1	79	86	78
		2	86	91	92
EF-689	4.0	1	87	91	84
		2	89	93	87
EF-689	8.0	1	94	89	72
		2	93	91	86
XRM-3972	2.0	1	3	0	0
		2	0	0	0
XRM-3972	4.0	1	8	2	0
		2	6	7	2
XRM-3972	8.0	1	18	14	15
		2	12	12	8
2,4-DA	4.0	1	73	77	63
		2	54	68	83
2,4-DA	8.0	1	74	86	73
		2	61	87	89
Dicamba	4.0	1	60	67	78
		2	36	39	53
Check	...	1	0	0	0
		2	0	0	0

[a]All treatments included X-77 as surfactant at 0.25 percent v/v.
[b]First application May 25, 1988; second application June 6, 1988.
[c]LSD = 13 ($p = 0.05$).

Table 2. Control of Canada Thistle

Herbicide[a]	Rate oz a.i./A	Application time[b]	Canada thistle control[c] weeks after application 2	4	8
			........*percent*........		
XRM-3972	1.0	1	47	65	67
		2	38	49	47
XRM-3972	1.5	1	45	61	65
		2	..	..	..
XRM-3972	2.0	1	62	78	78
		2	56	62	66
XRM-3972	4.0	1	78	89	85
		2	64	73	74
XRM-3972	8.0	1	90	97	93
		2	66	79	82
EF-689	1.0	1	2	0	0
		2	..	..	..
EF-689	2.0	1	0	0	3
		2	13	20	10
EF-689	4.0	1	2	0	7
		2	20	25	18
EF-689	8.0	1	5	0	0
		2	34	26	18
2,4-DA	4.0	1	27	47	25
		2	37	49	48
2,4-DA	8.0	1	45	61	58
		2	45	60	61
Dicamba	4.0	1	50	63	58
		2	49	56	50
Triclopyr	1.0	1	20	15	13
		2	24	30	27
Check	...	1	0	0	0
		2	0	0	0

[a]All treatments included X-77 as surfactant at 0.25 percent v/v.
[b]First application May 25, 1988; second application June 17, 1988.
[c]LSD = 10 (p = 0.05).

Notes

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